FINAL REPORT

FURTHER INVESTIGATION OF THE VALIDATION OF PROCEDURES FOR ESTIMATING INSTANTANEOUS ROAD LOAD

Prepared For:

TRANSPORT CANADA
ROAD SAFETY AND MOTOR VEHICLE REGULATIONS DIRECTORATE

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17. Abstract

The purpose of this project was to perform additonal analysis of the procedures for estimating the instantaneous road load on passenger vehicles. Road gradient measuring system verification testing was previously performed under TC contract number T8080-6-6100/01-SZ (W.R.Davis Report No. 87-46.2).

The data obtained from previous on-road testing using the Data Acquisition System and including the Instantaneous Road Load Measuring System and the Gradient Measuring System, was reviewed and found to contain unacceptable high velocity and road load fluctuations. The total road load as determined using the gradient system as a result, was different than the total road load as measured with the wheel torque transducer system.

A method for determining the cause(s) for the above was developed and a test program undertaken to verify the determined causes.

The causes as determined include: Data Acquisition hardware failures, sampling rate and resolution limitations, and mechanical friction in the speedometer cable housing. A method to reduce the magnitude of the velocity fluctuations resulting from problems encountered during data collection was developed. This procedure was shown to be successful in reducing the velocity fluctuations and resultant calculated road load without introducing phase shifts or compromising transient response levels.

Recommendations are made for optimizing the data collection and reduction, means of measuring and recording velocity data, and possible improvements to the gradient.

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17. Resume

Ce projet a pour objet d'effectuer une analyse supplémentaire des procédures servant à determiner la valeur instantanée de la résistance globale au roulement sur les automobiles. Un essai de vérification du systéme de mesure de la pente de la chaussée avait été effectué en vertu du contrat du TC, numéro T8080-6-6100-01-SZ (Rapport de W.R. Davis numéro 87-046.2).

Les données, obtenues à l'aide des essais de route antérieurs effectuées au moyen du systéme d'acquisition de données et comprenant le systéme de mesure de la valeur instantanée de la résistance globale au roulement et la systéme de mesure des pentes, ont été examinées, et l'on a constaté qu'elle contenaient des variations de vitesse et de résistance au roulement trop élevées. La résistance globale au roulement déterminée par le systéme des pentes était différente de celle mesurée au moyen du systéme de transmetteur des couples aux roues propulsives.

On a élaboré une méthode servant à déterminer la (les) cause(s) de ce qui précéde et l'on a entrepris un programme d'essai pour vérifier celles-ci.

Les causes déterminées comprennant les éléments suivants : pannes du matériel d'acquisition de données et frottement mécanique dans le logement du câble de l'indicateur de vitesse. On a mis au point une méthode servant à réduire la grandeur des variations de vitesse résultant des problémes rencontrés durant la réunion de données. Cette procédure a permis de réduire les variations de vitesse et la résistance au roulement résultante calculée sans causer de décalages de phases ni de niveaux de réaction transitoire compromettante.

On recommende d'optimiser la réunion et la réduction de données, les méthodes de mesure et d'enregistrament des données relatives à la vitesse et des améliorations éventuelles de la pente.

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1.0 INTRODUCTION

This report was prepared by W.R. Davis Engineering Ltd. for work which was performed for Transport Canada under TC contract number T8080-7-5300/01-SZ.

The purpose of this project was to perform additional analysis of the procedures for estimating the instantaneous road load on passenger vehicles.

The results of previous work by Davis Engineering showed that the instantaneous road load and road gradient could be measured and predicted successfully. Some areas still required further investigation, however, such as variations in the measured and calculated road load with respect to time.

1.1 BACKGROUND

The road gradient measuring system verification testing was performed under TC contract number T8080-6-6100/01-SZ (DAVIS Report No. 87-46.2). This testing provided summer and winter instantaneous road load data based on the two instantaneous road load measuring systems.

During the data analysis procedures, it was observed that the vehicle road load as measured and calculated by the wheel torque measuring system was different than the road load as determined by the vehicle distance, velocity and gradient measuring system.

The difference consisted of the vehicle road load fluctuations. As a result, it was decided to investigate the possible cause(s) for this difference in predicted and measured vehicle road loads.

1.2 OBJECTIVES

The objectives of this project were to determine the reasons for the observed differences between the predicted and measured road load values, and to propose appropriate changes to the instrumentation or the estimation procedure which would ensure a closer correlation between the two methods of road load determination.

1.3 SCOPE

The scope of this work was limited to investigating the causes of road load magnitude differences between the road load as measured with the wheel torque transducer system and the road load measured with the distance, speed and gradient measuring system.

This work included data acquisition system (DAS) investigations, software, hardware, wheel torque measuring system investigations, and vehicle distance, speed and gradient measuring system investigations.

Recommendations for future testing and/or system modifications are also included.

2.0 METHOD OF ANALYSIS

The planned method of analysis and troubleshooting was as follows:

- Replot selected summer and winter road load data in the form of vehicle force versus time, including vehicle velocity.
- analyze relationship between the two forces (as determined from wheel torque sensor and from vehicle distance, velocity and gradient data) and the recorded vehicle velocity.
- software data reduction and road load force calculation procedure verifications.
- depending on the outcome of the data analysis, formulate further data manipulation and component and/or vehicle testing.

The resultant method of analysis and troubleshooting based on the above work was developed as follows:

- a backup vehicle velocity measurement system, was developed using the wheel torque sensor magnetic pickup. DAS modifications and software changes were required.
- bench testing of new distance velocity measuring system to obtain accuracy and response information.
- on-road calibration to compare and evaluate the two velocity measuring systems.

After several unsuccessful calibration runs, it became evident that the original distance velocity measuring system was not stable. The new wheel torque velocity measuring system supplied repeatable distance data.

The DAS was brought back into the laboratory and checked out. A hardware failure problem in the distance velocity circuit was located and repaired.

More calibration runs were performed and repeatable distance values were obtained. The velocity readings were not stable however. The velocity was also calculated on a second by second basis from the recorded distance data with a lower resultant fluctuation than the measured velocity.

At this time it was decided to remove the distance/velocity measuring system from the vehicle along with the DAS, and to perform bench testing on the total system to determine its accuracy and dynamic response characteristics.

During the bench testing of the distance/velocity measuring system a problem with the casing and cabling was found.

The system was repaired, bench tested and reinstalled in the vehicle.

A calibration sequence was performed with repeatable distance and velocity readings.

Based on the foregoing work a method of correcting the previously collected summer and winter cycle data was developed.

The objective was to eliminate erroneous velocity spikes caused by the faulty distance speed measuring system, and to introduce a software equivalent close to a 1 Hz filter on the velocity data. The 1 Hz is based on the fact that the wheel torque data has a 1 Hz filter installed in the hardware.

Once the velocity correction program was operational, plots of force versus time were created so that the road load force as calculated by the DAS and the wheel torque measuring systems could be compared.

3.0 RESULTS OF ANALYSIS, TESTING ACTIVITIES AND ORIGINAL DATA OPTIMIZATION

3.1 ORIGINAL DATA ANALYSIS

The original summer and winter data was re-analyzed to obtain some indication and insights into the calculated power or force fluctuations with respect to time as calculated by the DAS.

Plots of force vs time, as well as velocity vs time were created. Both overall and sections of the test cycle were plotted. See Figures 3.1 to 3.5.

Careful examination indicated a vehicle velocity fluctuation, resulting in a large force vs time oscillation second by second.

The software data reduction programs were checked over for completeness and calculation flaws, with no apparent problems located.

The vehicle power and/or force as measured and recorded by the wheel torque sensors was analyzed with no indication of problems with the measurement system.

3.2 TESTING ACTIVITIES

Based on these results, a second vehicle velocity measurement system, which would measure the vehicle wheel speed directly, was designed and installed. The existing digital fuel consumption measurement channel was modified and used for this application. The low level output from the Hall-Effect Sensor was amplified and conditioned to provide a compatible output with the existing fuel channel. Software was developed to display and record the wheel speed and the predicted road load based on this wheel speed. The new system was bench tested and provided repeatable distance and velocity data.

The results of the on-road calibration procedures were negative. The optical sensor system was not recording repeatable distance data. The DAS and velocity measuring systems were removed from the vehicle and brought into the electronics laboratory.

During troubleshooting procedures a hardware failure was found in the optical distance/velocity sensor circuit. An operational amplifier (op-amp) was malfunctioning. The troubleshooting procedure consisted of inputting a known frequency into the speed input and monitoring the output for stability. The output was not stable. A known number of pulses was also fed into the input while monitoring the recorded distance value. The distance value recorded changed for each trial. A modified software program was used to output the actual count from the optical sensor, so that the divider circuit could be verified.

The op-amp was replaced and the circuit operation was fully verified to ensure an accurate and complete pulse count. Once accurate and repeatable data was obtained the DAS system was reinstalled in the vehicle.

Further on-road calibration testing was conducted. The on-road calibration data indicated that the total count or distance was repeatable, however the velocity signal was still oscillating in the range of plus or minus 10 to 15 km/hr which was unacceptably high.

At this time the entire DAS and distance/velocity measuring system was removed from the vehicle for laboratory troubleshooting.

The laboratory test results indicated a random frequency variation in the output from the distance/velocity sensor. Further testing indicated a mechanical backlash/friction problem between the speed cable coupling at the optical sensor and casing material. The clearance problem was rectified and the system verified for an oscillating signal, with positive results. Maximum oscillations were ±0.3 km/hr. The DAS and velocity measuring system was reinstalled in the vehicle and tested.

The DAS and velocity measuring systems were calibrated with positive results. The two velocity measuring systems were also compared to each other with the optical system showing better accuracy than the wheel magnetic pickup velocity system.

3.3 ORIGINAL DATA OPTIMIZATION

A method to correct for the recorded velocity oscillations during the summer and winter testing was investigated and developed. The approach was to first select and identify erroneous velocity peaks, average only those peaks so identified. Table 3.1 contains a logic table showing the method of identifying suspect velocity data peaks. Once the peaks were identified and filtered the overall data was software filtered by a moving three point method. This method approximates a 0.33 Hz filter.

Figures 3.8 to 3.25 contain plots of the uncorrected and corrected road load force vs time, and velocity vs time. As can be seen from these plots the selective averaging and continuous averaging do not delete any data. In the transient conditions no apparent loss of accuracy is shown by using this type of filtering.

TIME (SEC)	SIGN OF ACCELERATION SEQUENCE 1	SEQUENCE 2	SEQUENCE 3	SEQUENCE 4
1	+	-	-	+
2	-	+	-	+
3	+	-	+	-
4	-	+	-	+
5	+	-	-	+

Note: The time 3 velocity is replaced by the average of the 5 when the above acceleration sign sequences are located.

TABLE 3.1 LOGIC TABLE FOR IDENTIFYING ABNORMAL VELOCITY PEAKS

4.0 DISCUSSION OF FINDINGS

The following is a summary of findings and observations:

- the summer and winter data contained a variable amount of oscillating velocity data
- the winter data contained a larger amplitude velocity oscillation as compared to the summer data
- an op-amp in the DAS velocity circuit experienced performance degradation resulting in the output voltage falling below the minimum high level input voltage threshold required by the following divider chip. The time of occurance and magnitude of the failure are not known
- a clearance and backlash problem, caused intermittent cable and optical sensor frequency oscillations
- instantaneous error excursions above and below actual speed exactly cancel out over longer intervals, so heavier digital filtering produces more accurate data at the expense of real transient responsiveness
- the torque sensor based wheel speed measuring system provided a velocity signal with a higher amplitude of oscillation than the DAS optical sensor vehicle speed system, once the op-amp and cable clearance problem were repaired
- the summer and winter data both contained velocity data with oscillations not representative of the actual vehicle velocity profile
- the velocity and road load force data collected can be selectively filtered by software means, without losing any data points, using a level of filtering that is comparable to the wheel torque sensor filtering.

Based on the above findings and observations it is felt that the summer and winter data is useful and can be filtered by software means to more closely match the filtered wheel torque sensor data. (1 Hz filter on wheel torque sensor data).

Improving the accuracy of instantaneous speed measurements can be accomplished through implementation of one or more of the following concepts:

1) increase the resolution of the speed/distance transducers (obtain more pulses per kilometer),
2) increase the resolution of time measurement beyond 10 bits,
3) reduce the backlash in the transducer coupling to less than one pulse (direct coupling is possible but implies monitoring at one wheel),
4) compensate for wheel diameter variations by calibrating distances at various speeds and turning radii,
5) obtain a time average of speed over each sampling interval (and log it as representing the speed at the mid-point time of the sampling interval).

4.1 SPEED MEASUREMENT DISCUSSION

Three techniques are currently used to measure vehicle speed as outlined below. The fourth description refers to an optimized combination which would perform better. A comparison of features is included in Table 4.1.

1) Speedometer cable with optical transducer putting out 339,000 pulses per kilometer. The total period of 16 consecutive pulses is measured to a resolution of 20 ms to obtain instantaneous speed. Up to 20 of these instantaneous speeds (not necessarily consecutive) are averaged each second to obtain a sampled speed.

2) Magnetic pickup on a wheel mounted gear putting out 37,000 pulses per kilometer. The number of pulses (distance) per second are counted. The one second timer is accurate to ±.5 ms.

3) The optical sensor output is run through a frequency to voltage converter which creates a voltage that is proportional to speed. This is done to allow analog calculation of wheel acceleration for use in gradient compensation.

4) A Hall effect sensor (no low speed dropout) could be used to remotely detect gear teeth directly at the wheel with no possibility of backlash. The number of pulses in each second could be counted exactly and the exact time for these pulses to occur could also be measured (since the last pulse edge may not coincide with the end of the one second period). Dividing these two accurate quantities will give an accurate speed averaged over the period.

	1	2	3	4
FEATURE	**PERIOD**	**FREQUENCY**	**VOLTAGE**	**TIME AND DISTANCE**
Low Speed dropout	No	Yes	No	No
Accurate at low speed	Yes	No	No	Yes
Accurate at high speed	No	Yes	Yes	Yes
More than .5 sec lag	No	No	Yes	No
Sensitive to backlash	Yes	No	No	No

TABLE 4.1 SPEED CALCULATION TECHNIQUES COMPARISON

Notes 1) The fourth technique, which is not in use yet is the only one to excel in all categories.
2) Backlash in the transducer coupling is always a problem which needs to be minimized, so the rating above just implies that instantaneous period measurement is extremely sensitive to it.

The implementation of technique 4 can be done with relatively small changes to software and hardware. The same transducer (optical) can be used if the coupling backlash can be eliminated.

4.2 GRADIENT DISCUSSION

The gradient system measures gradient by subtracting the wheel acceleration vector from the total acceleration vector in the vertical longitudinal plane. Unfortunately there are also significant influences from vehicle pitch and yaw which are not compensated for because of their complex relationships to vehicle speed, acceleration, loading, road bumps, cornering, braking, road camber, and wind. The other main problem is that the two signals being subtracted must have identical filtering and lag time constants or the resultant will have transient errors.

It is clear that the processed gradient signal has large errors under transient acceleration conditions, so the alternatives which may improve the data are:

1) develop an inexpensive inertial reference
2) measure the suspension travel to obtain pitch and yaw for compensation purposes
3) calibrate the vehicle and gradient system to allow post processing of the data and more accurate gradient recovery
4) use heavier filtering to reduce transient errors
5) accurately measure uniaxial vertical acceleration with respect to the plane of the wheel hubs (the suspension parameters may still need to be measured to compensate for bumps)
6) map the test routes with surveys, an inertial navigation system, or an inclinometer (travelling slowly).

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been made:

- a velocity oscillation problem occurred during the summer and winter testing, with the problem being more severe during the winter testing
- the cause of the velocity oscillation problem was due to a speed cable and optical sensor housing clearance, and/or an op-amp failure. The timing of failure and proportion of error introduced by each problem would be hard to define
- the summer and winter data can be software filtered, thereby reducing the observed variance in the measured and estimated road loads
- the optical velocity measurement system has adequate resolution for this application, i.e. instantaneous road load determination
- the wheel torque sensor wheel speed measuring system lacks the resolution to be useful for this application i.e. instantaneous road load determination
- improvements in matching of the two road load measurement techniques can be achieved by improving the speed measurement (accuracy and filtering) and/or by improving the gradient measurement system (especially during transient acceleration)

The following recommendations are made:

- the summer and winter data should be optimized by software filtering
- a more consistent velocity measurement system should be implemented
- a better gradient isolating system should be implemented.

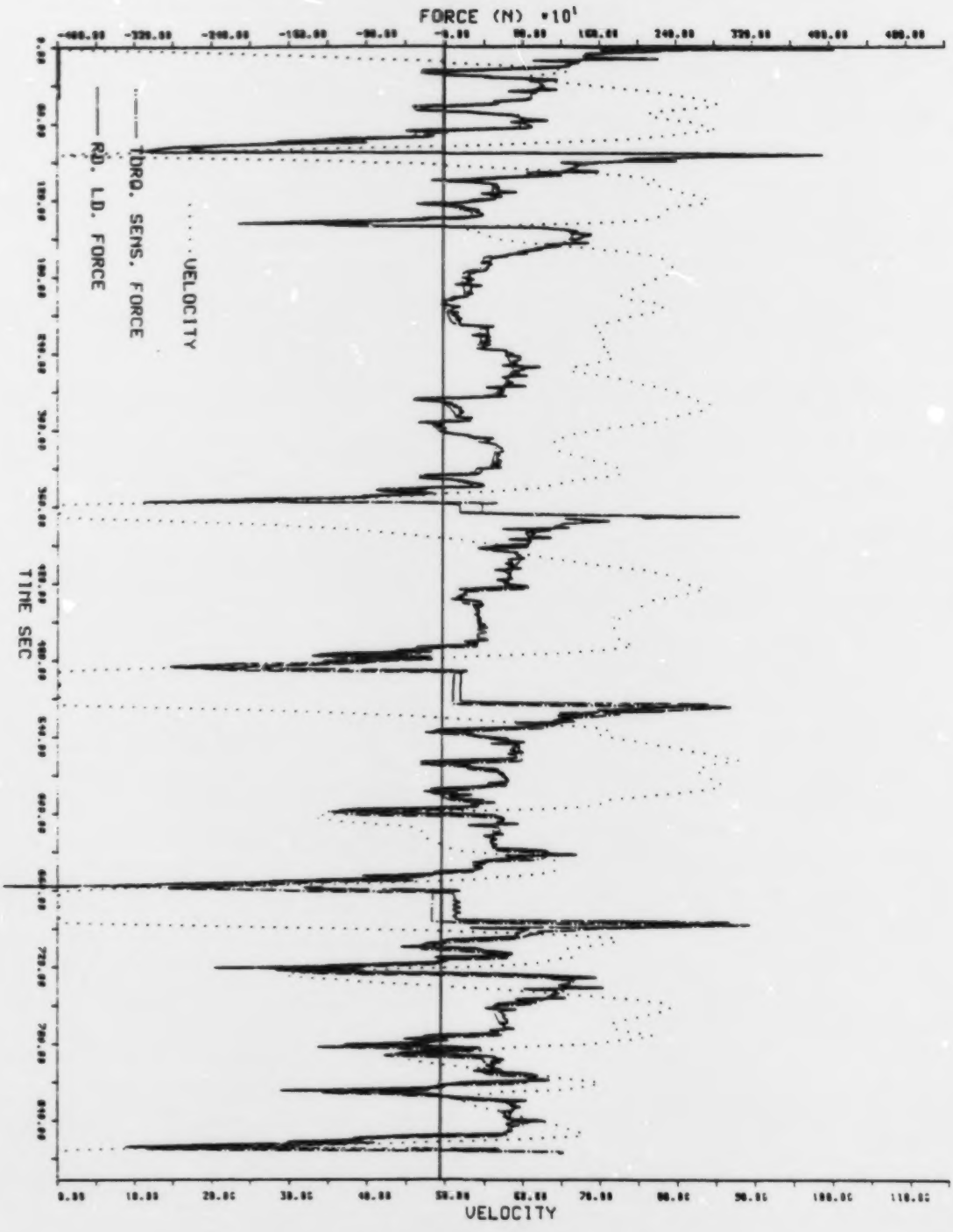

FIGURE 3.1 SUMMER DATA, FORCE VS TIME, AND VELOCITY VS TIME

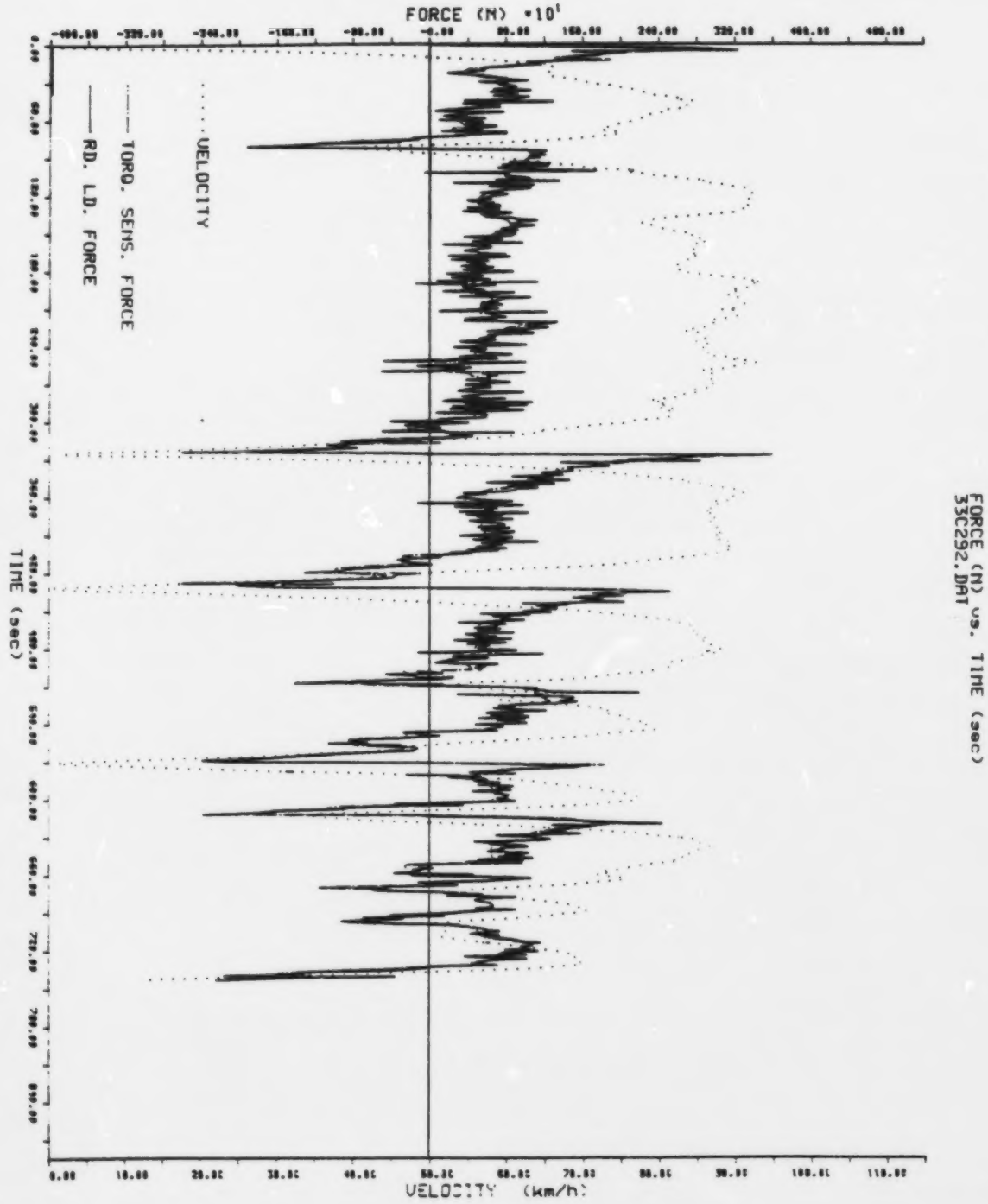

FIGURE 3.2 WINTER DATA, FORCE VS TIME, AND VELOCITY VS TIME

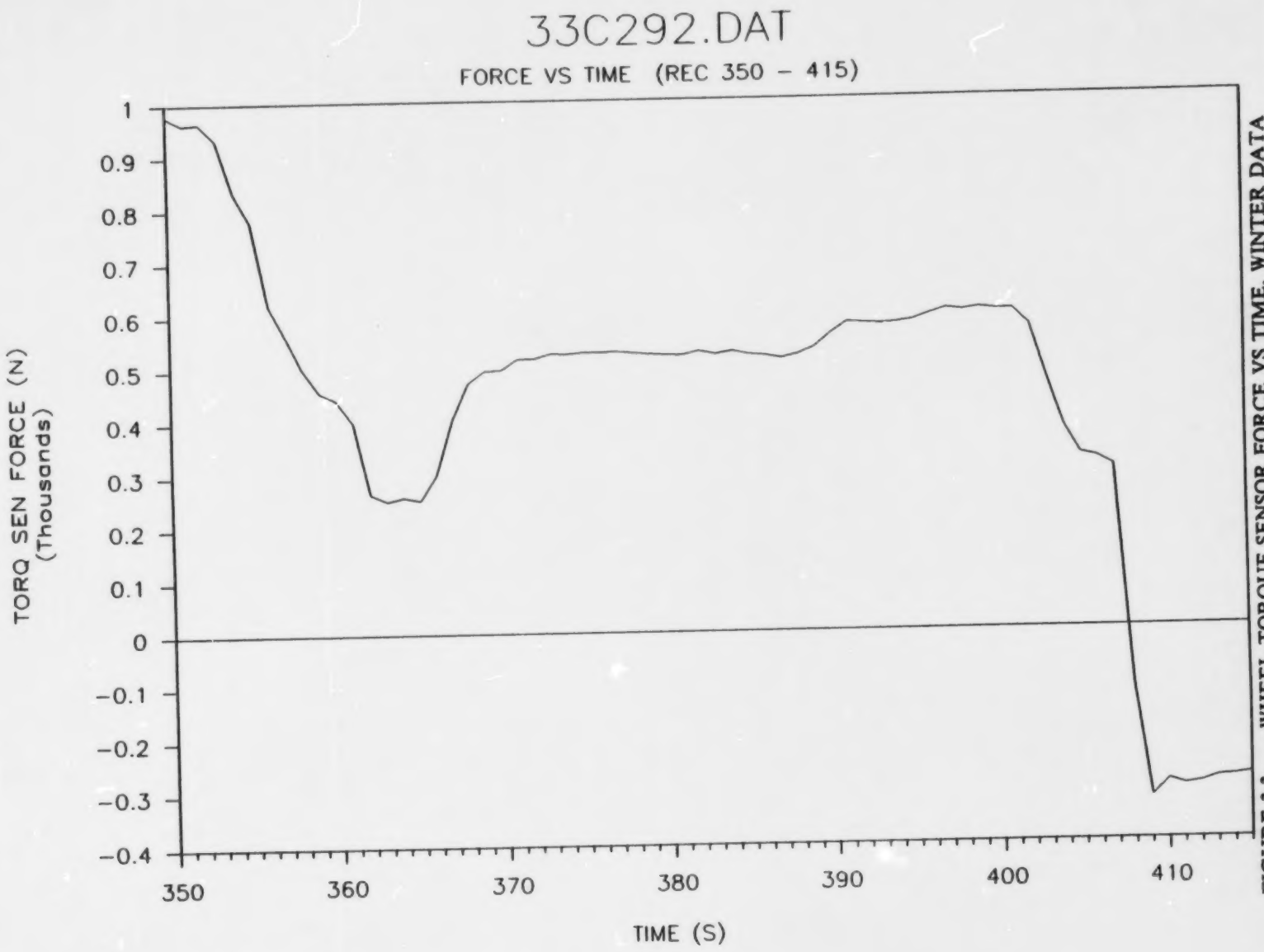

FIGURE 3.3 WHEEL TORQUE SENSOR FORCE VS TIME, WINTER DATA

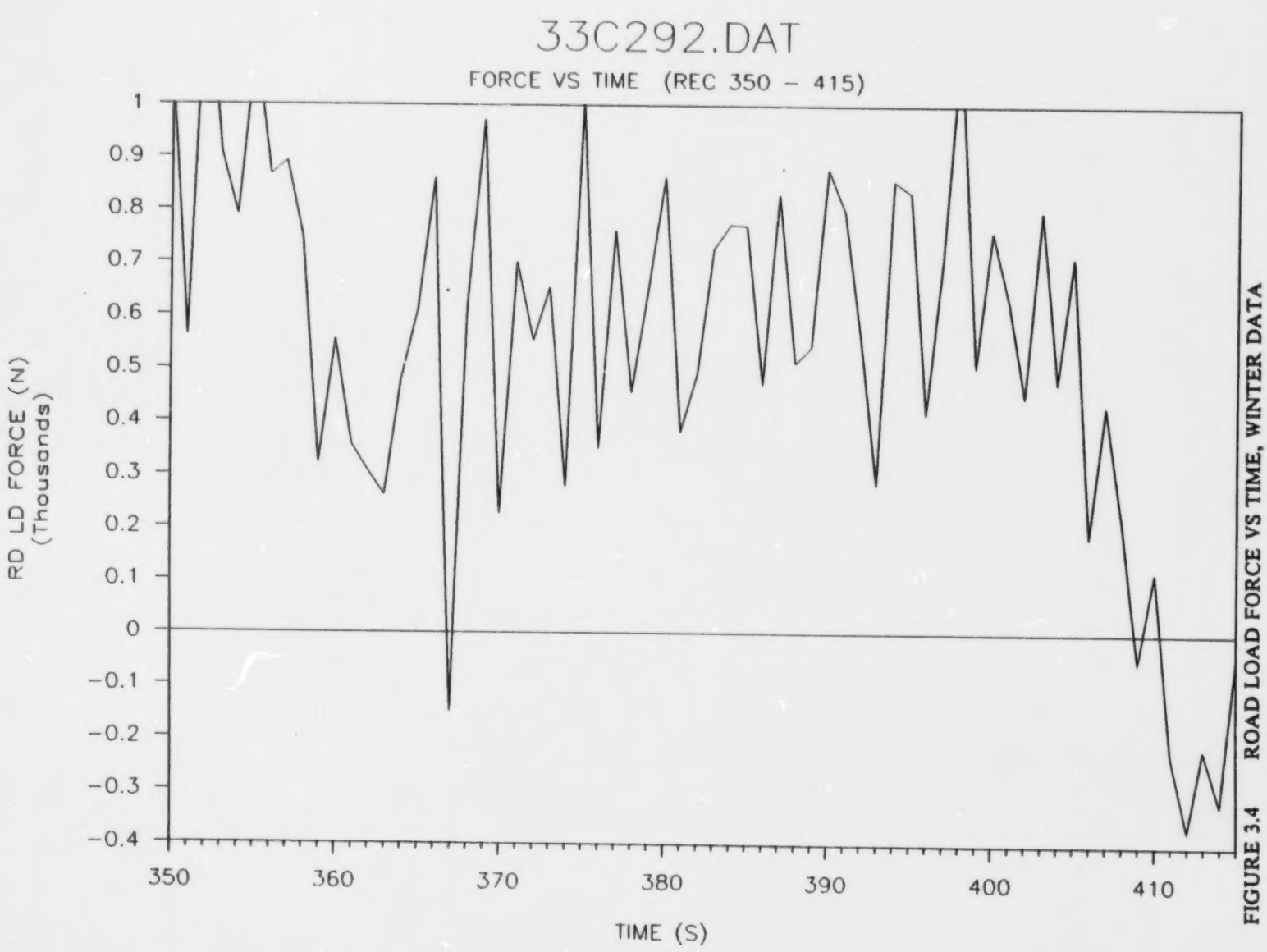

FIGURE 3.4 ROAD LOAD FORCE VS TIME, WINTER DATA

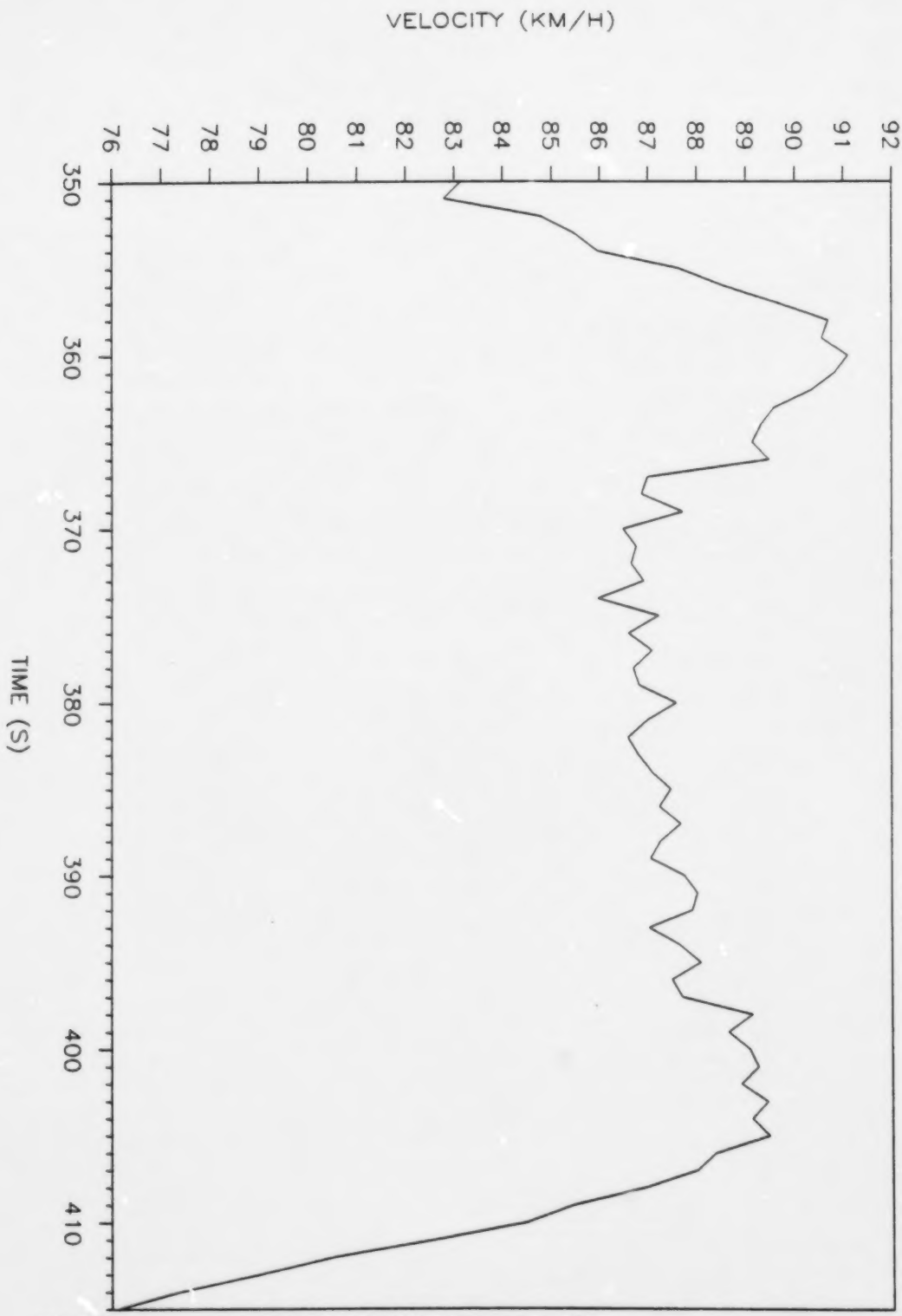

FIGURE 3.5 VELOCITY VS TIME, WINTER DATA

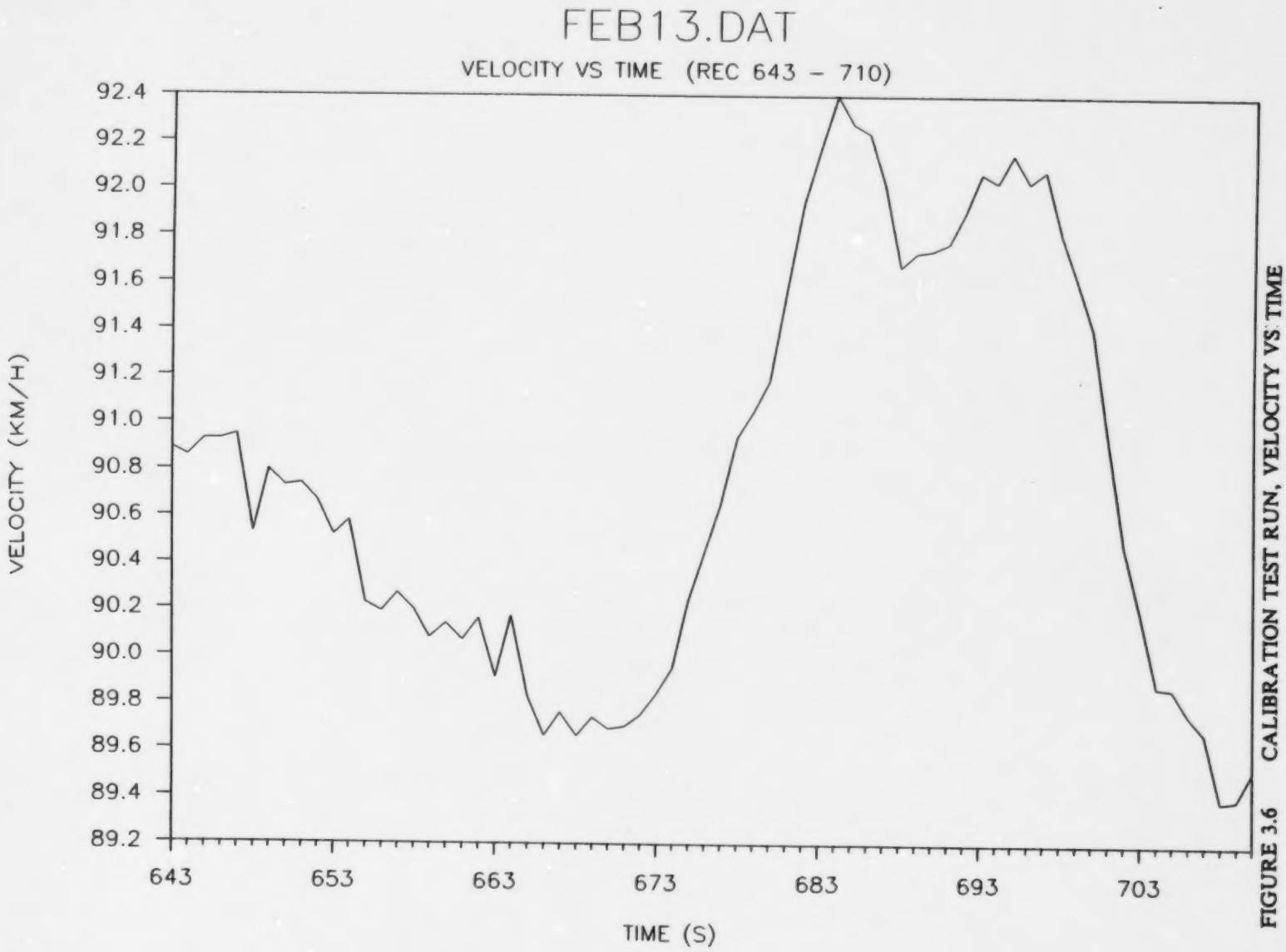

FIGURE 3.6 CALIBRATION TEST RUN, VELOCITY VS TIME

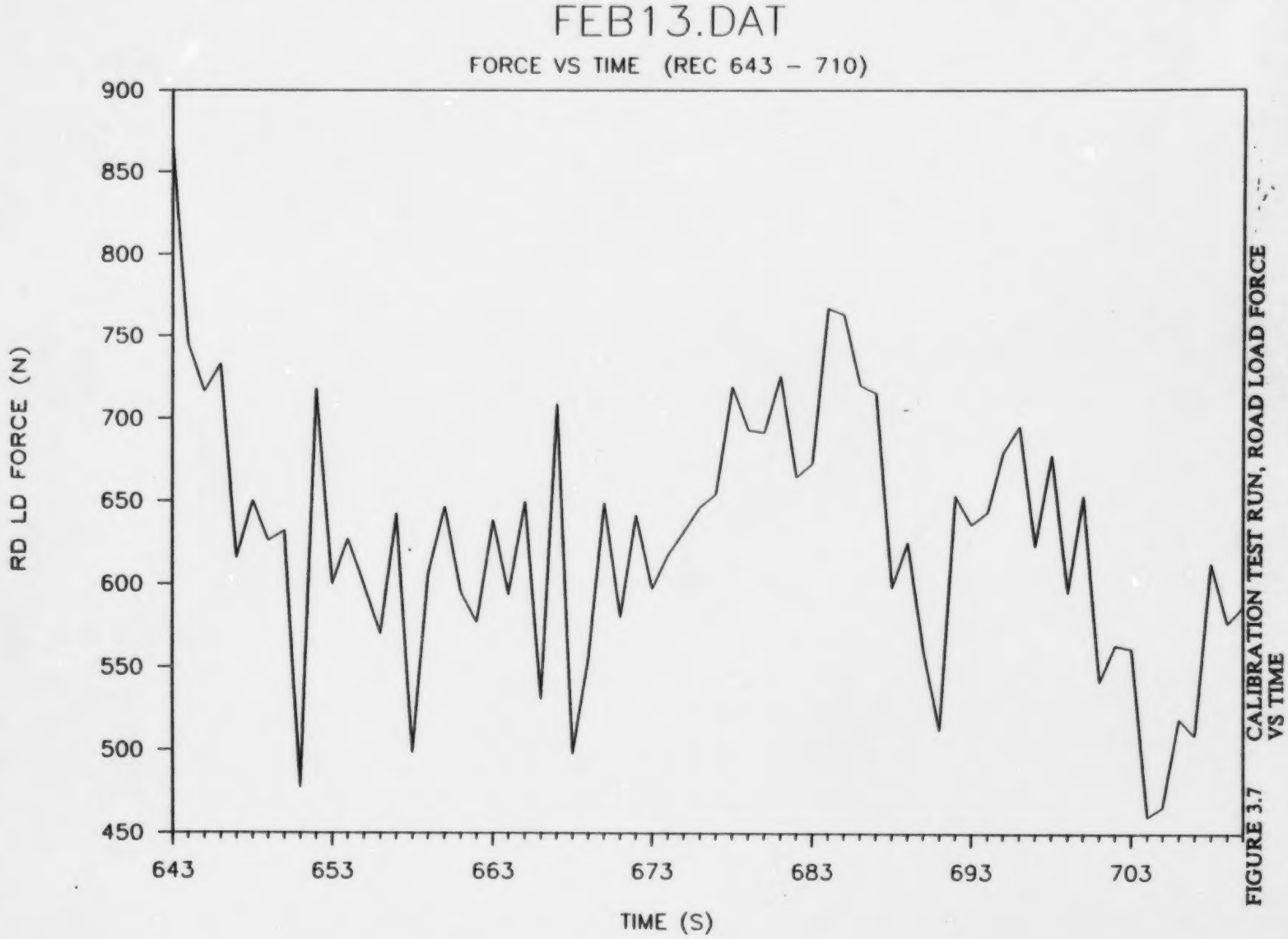

FIGURE 3.7 CALIBRATION TEST RUN, ROAD LOAD FORCE VS TIME

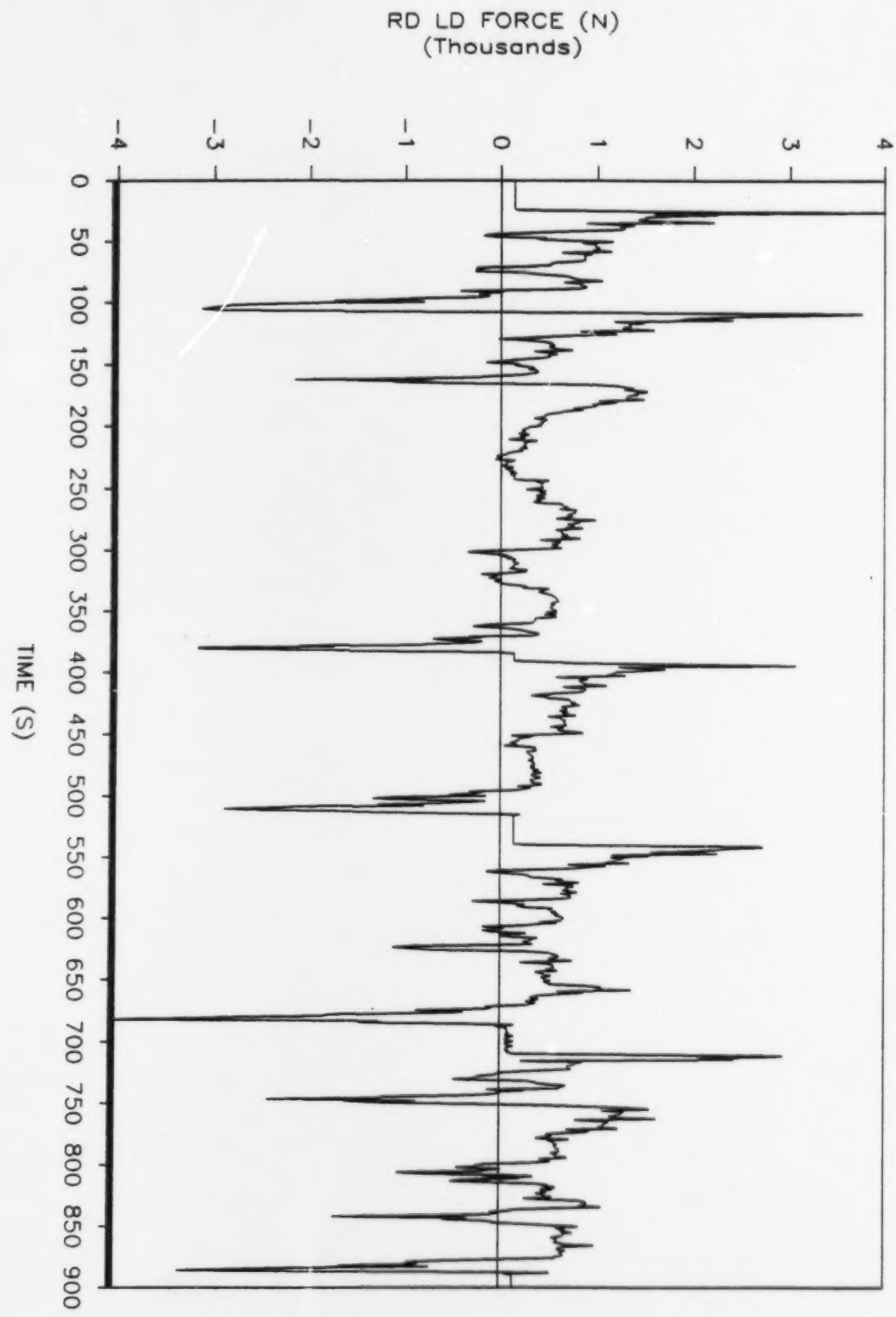

FIGURE 3.8 ROAD LOAD FORCE VS TIME, SUMMER DATA

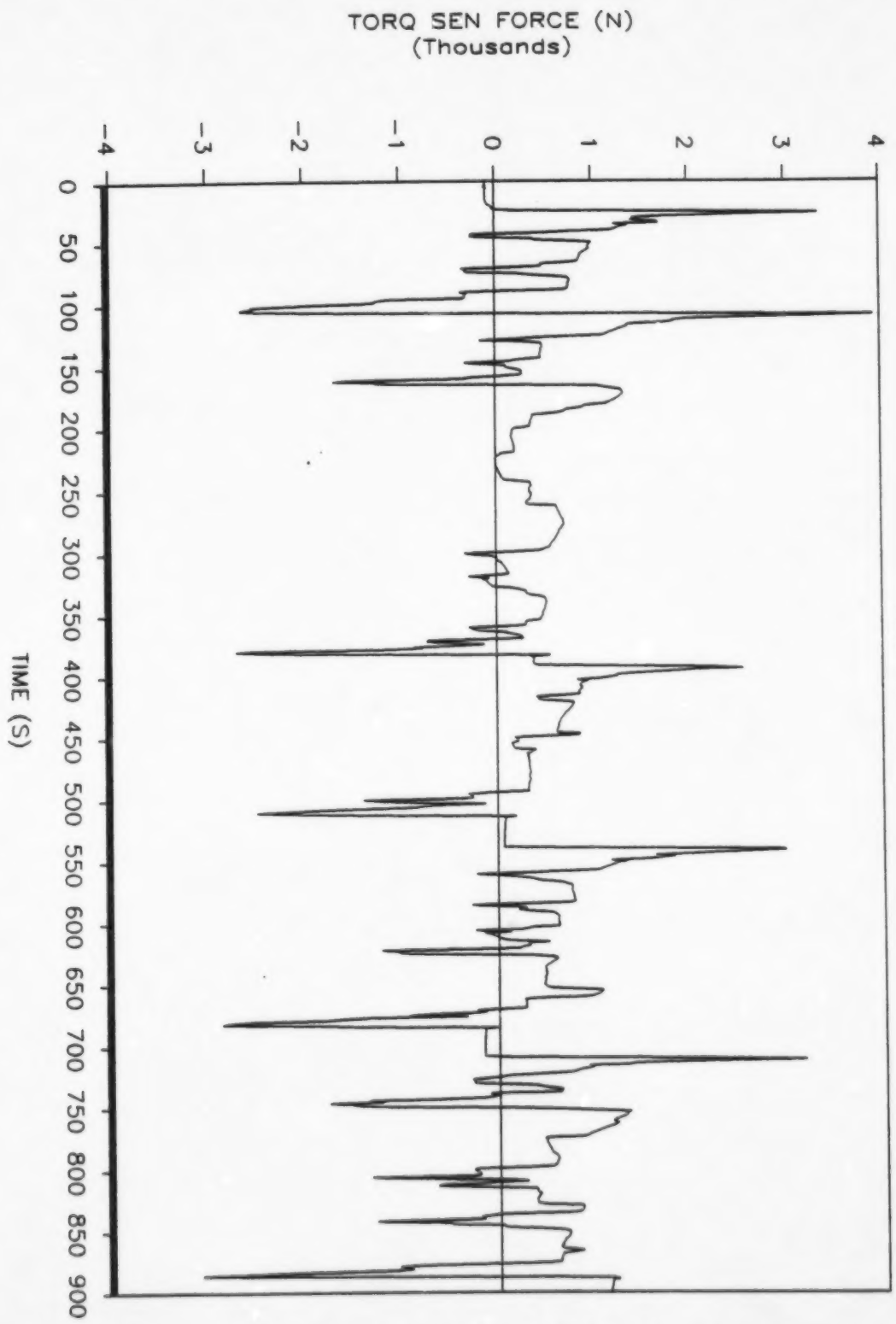

FIGURE 3.9 WHEEL TORQUE SENSOR FORCE VS TIME, SUMMER DATA

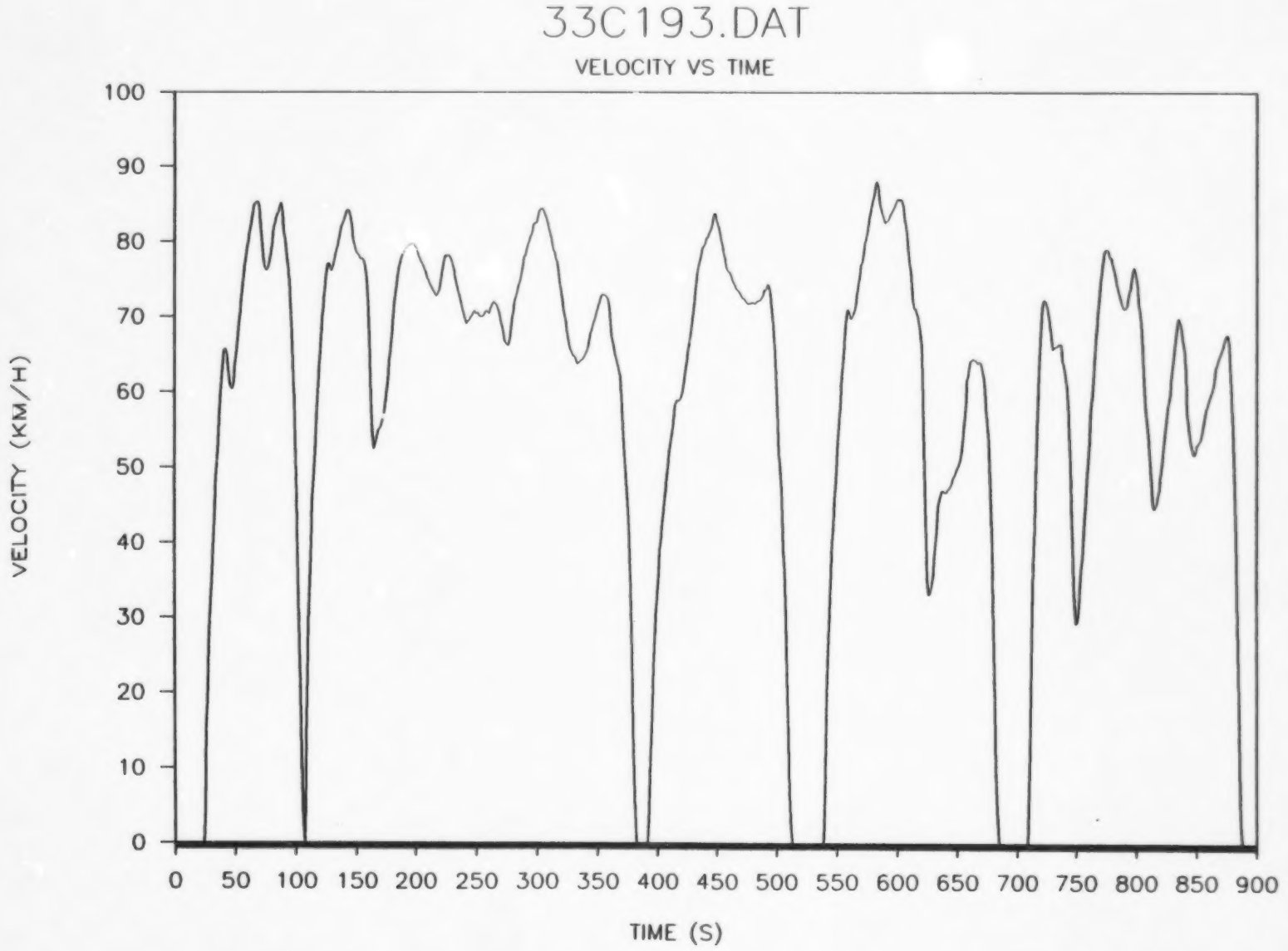

FIGURE 3.10 VEHICLE VELOCITY VS TIME, SUMMER DATA

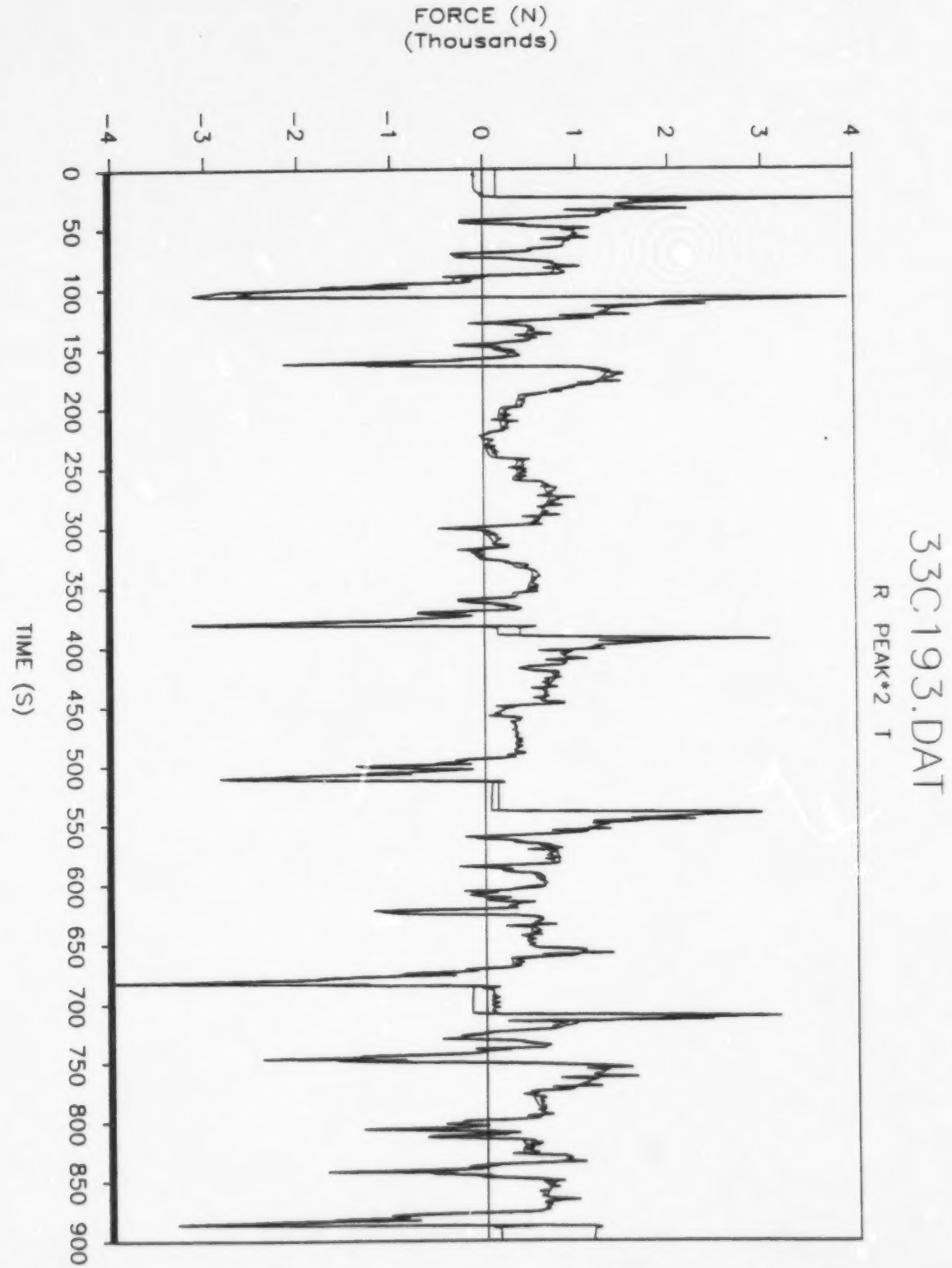

FIGURE 3.11 ROAD LOAD FORCE, PEAK FILTERED TWICE, VS TIME, AND WHEEL TORQUE SENSOR FORCE VS TIME, SUMMER DATA

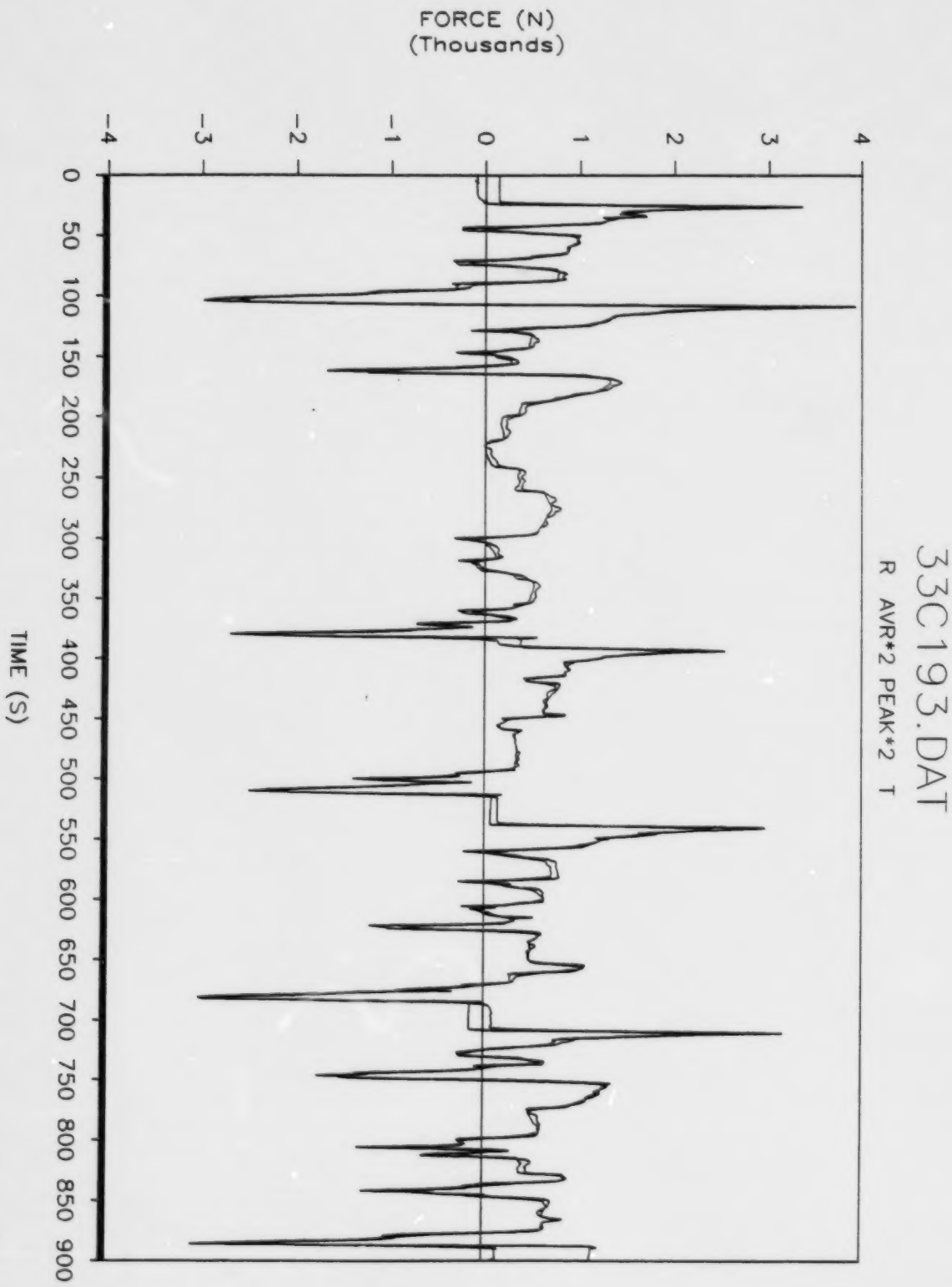

FIGURE 3.12 ROAD LOAD FORCE, PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, AND WHEEL TORQUE SENSOR FORCE VS TIME, SUMMER DATA

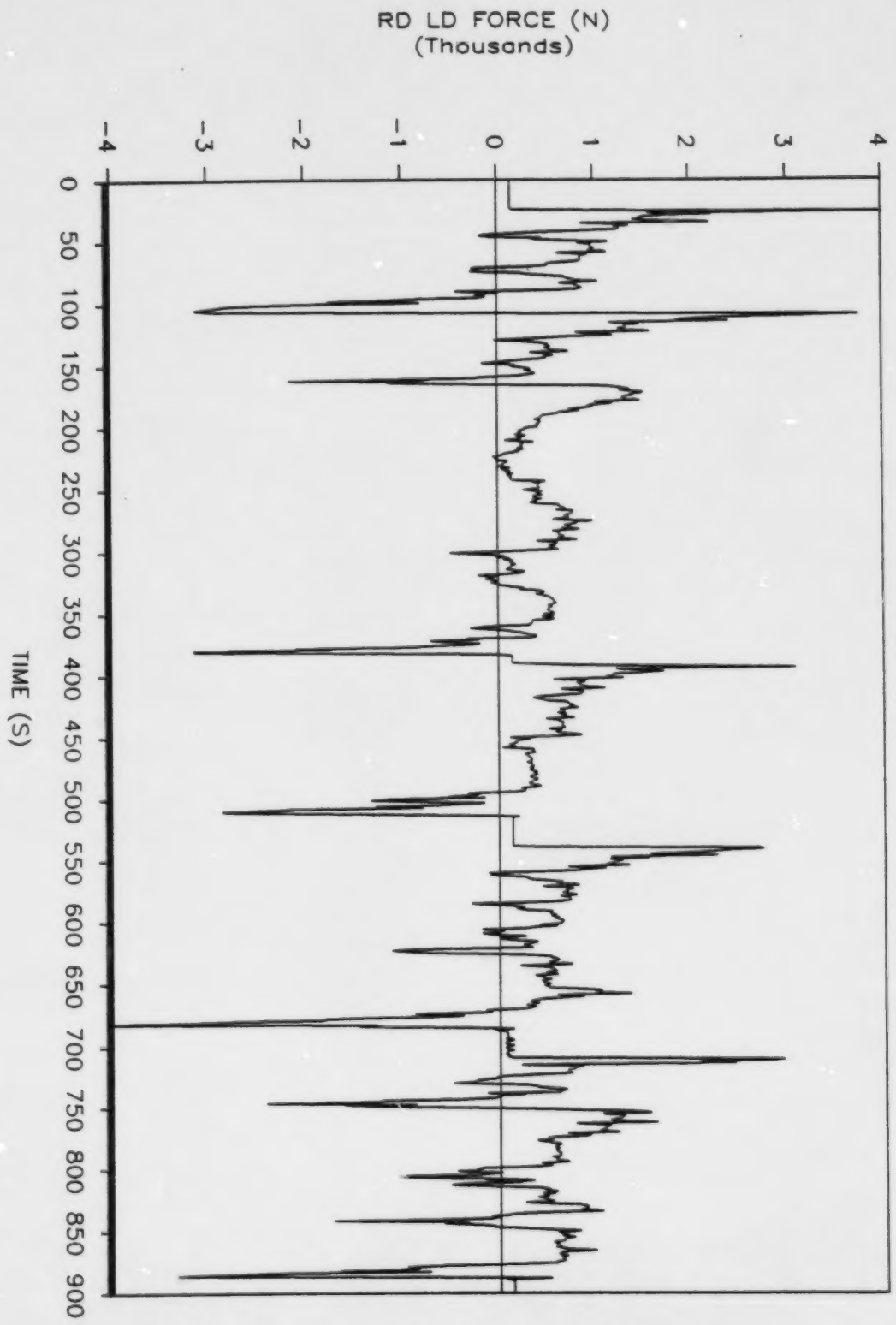

FIGURE 3.13 ROAD LOAD FORCE, PEAK FILTERED TWICE VS TIME, SUMMER DATA

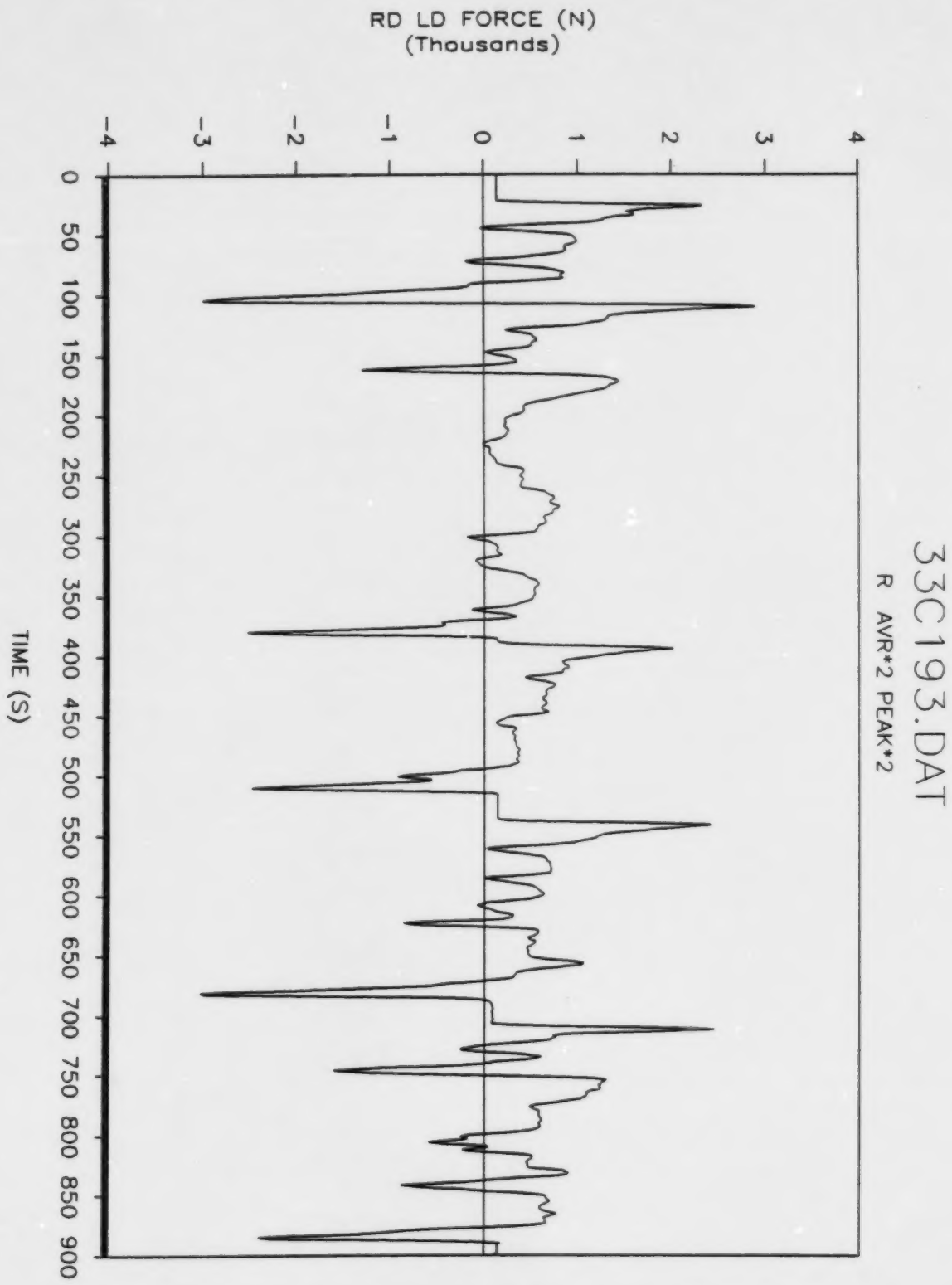

FIGURE 3.14 ROAD LOAD FORCE, PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, SUMMER DATA

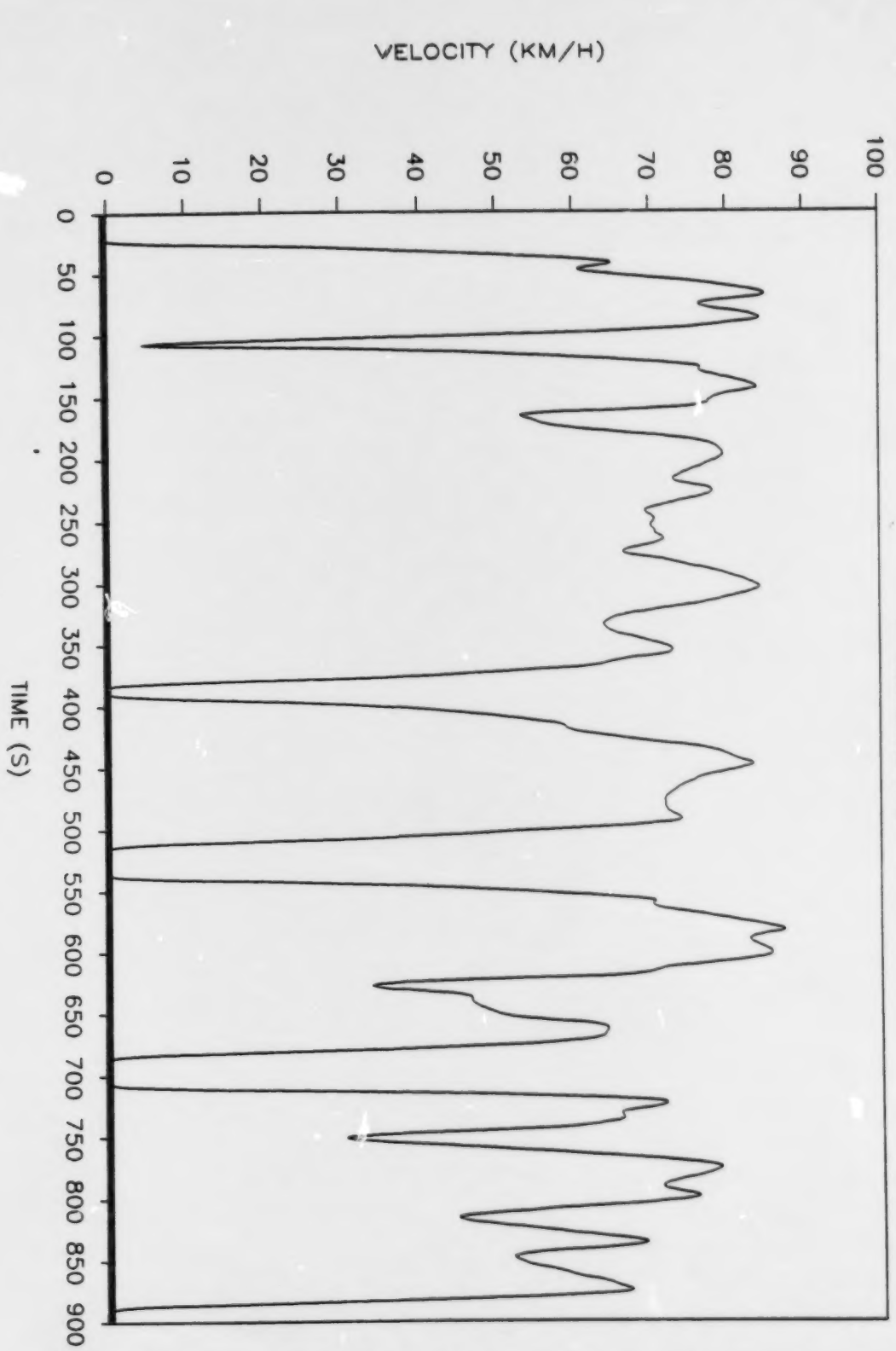

FIGURE 3.15 **VEHICLE VELOCITY, PEAK FILTERED TWICE VS TIME, SUMMER DATA**

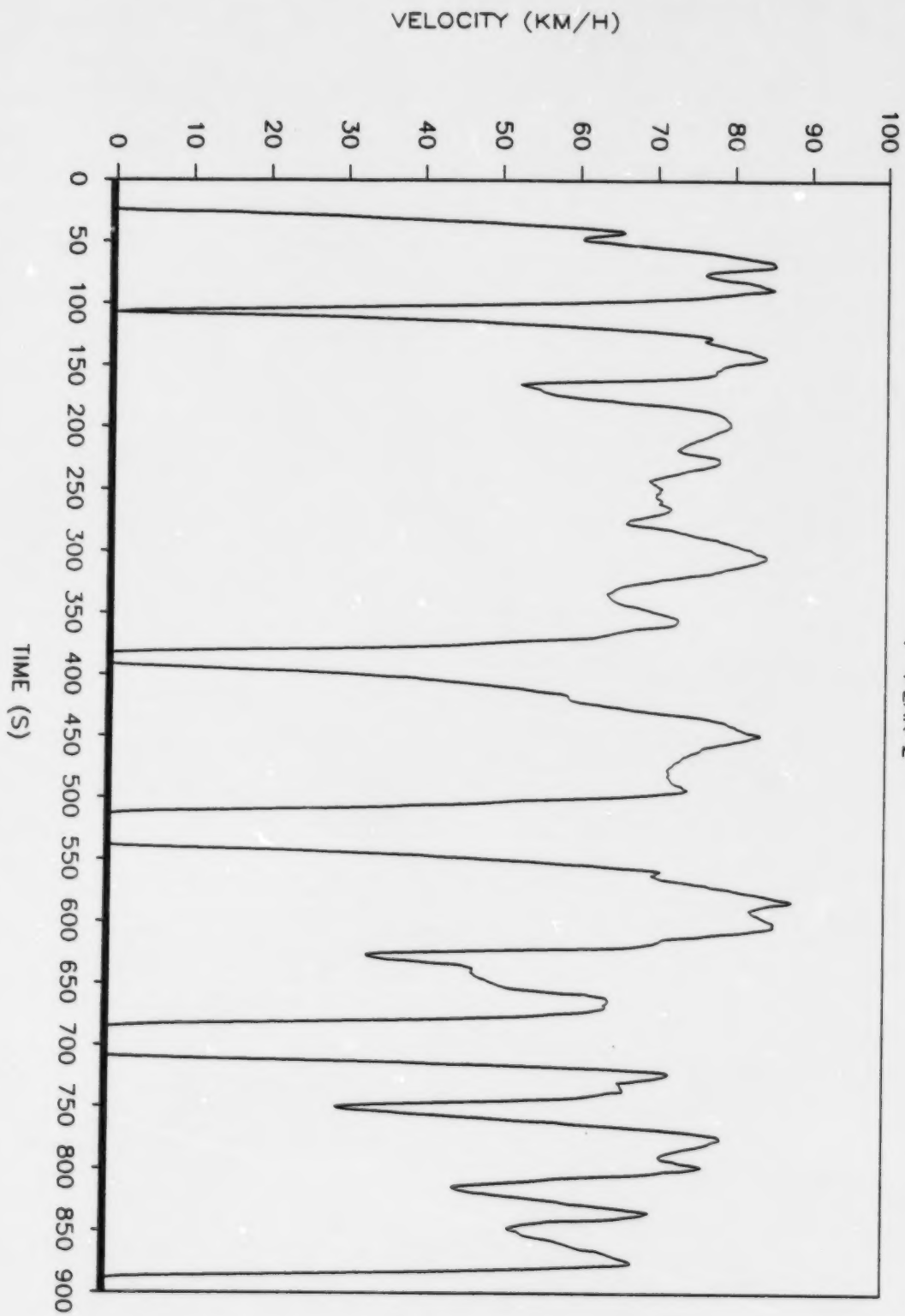

FIGURE 3.16 VEHICLE VELOCITY PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, SUMMER DATA

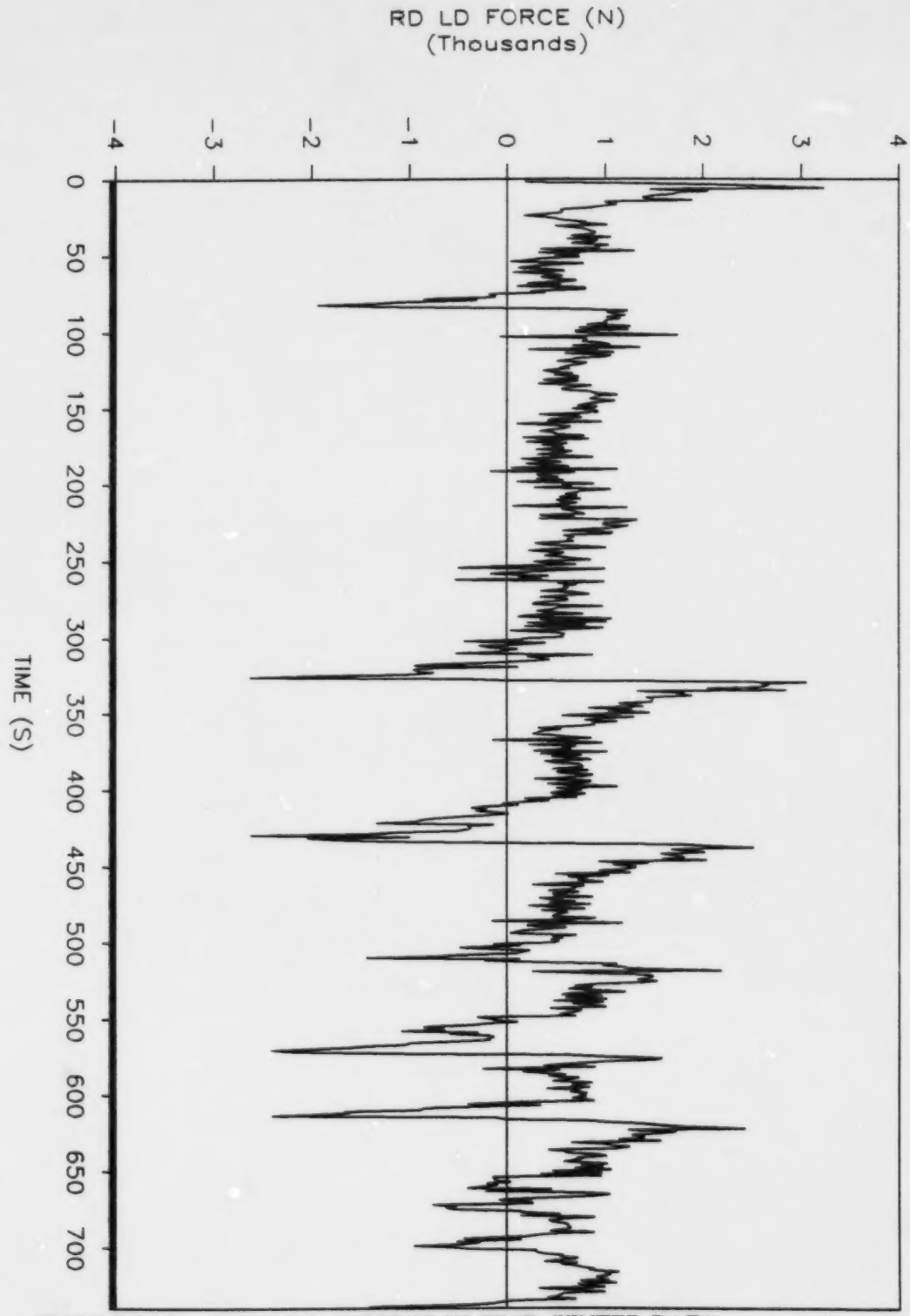

FIGURE 3.17 ROAD LOAD FORCE VS TIME, WINTER DATA

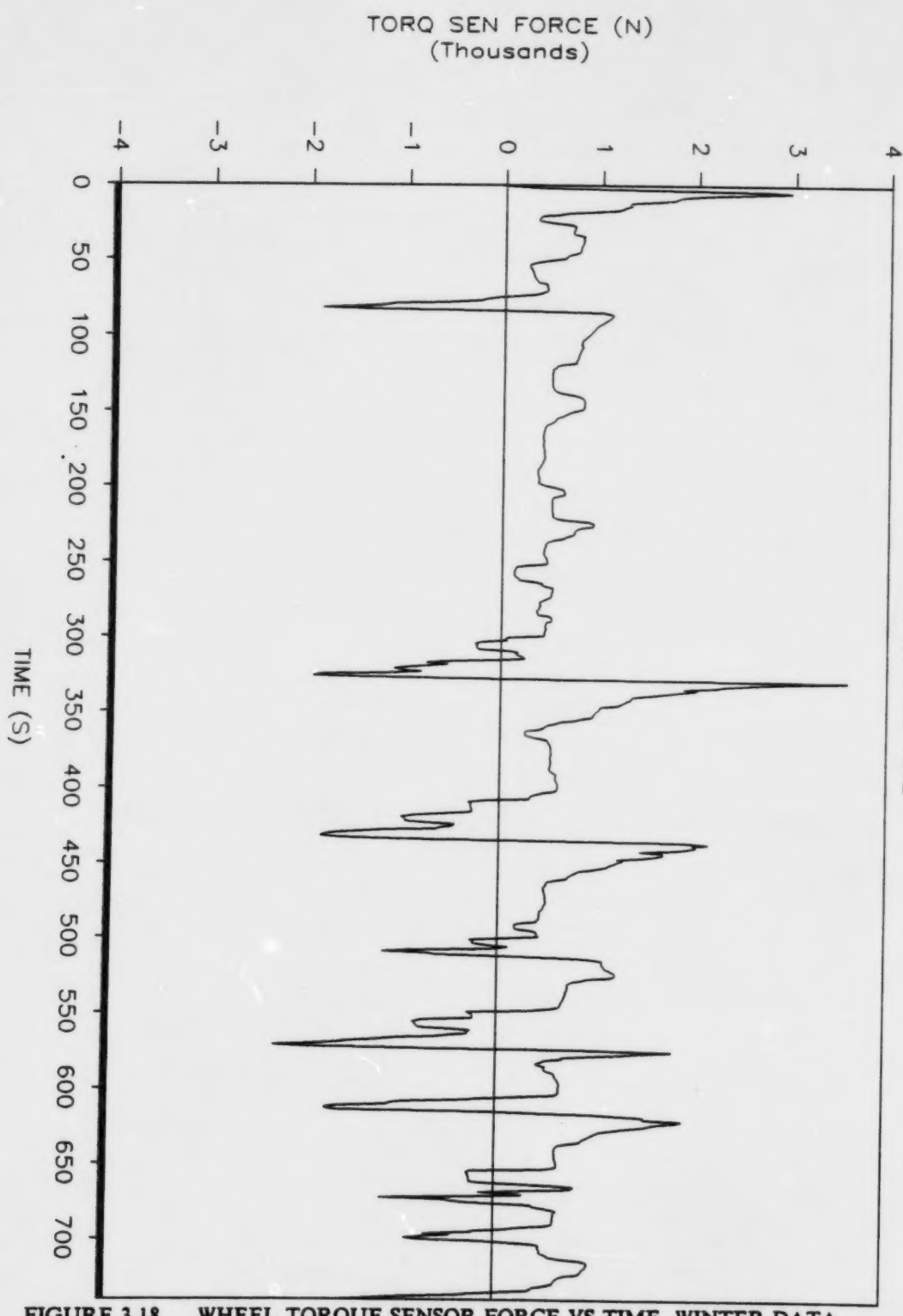

FIGURE 3.18 WHEEL TORQUE SENSOR FORCE VS TIME, WINTER DATA

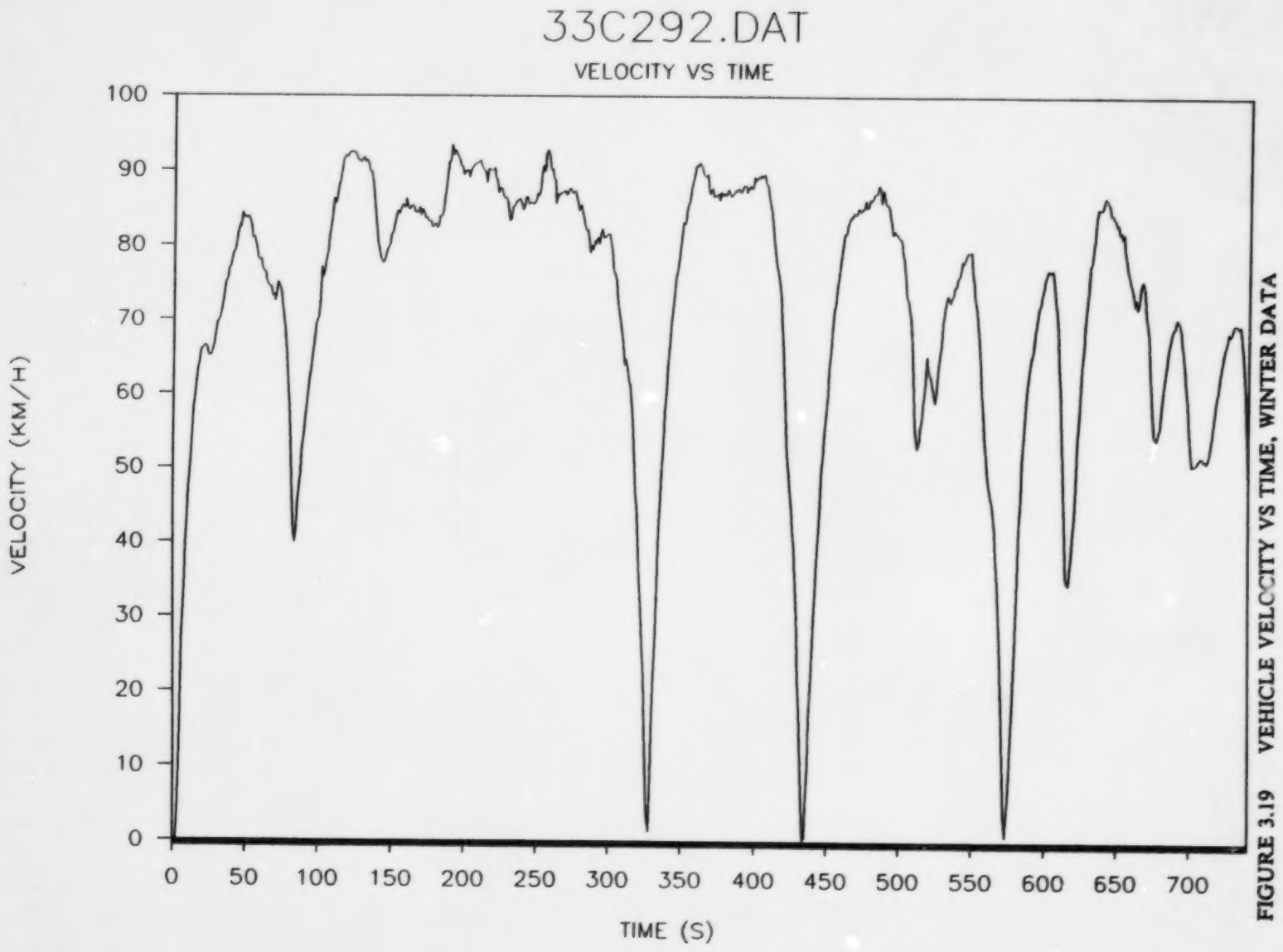

FIGURE 3.19 VEHICLE VELOCITY VS TIME, WINTER DATA

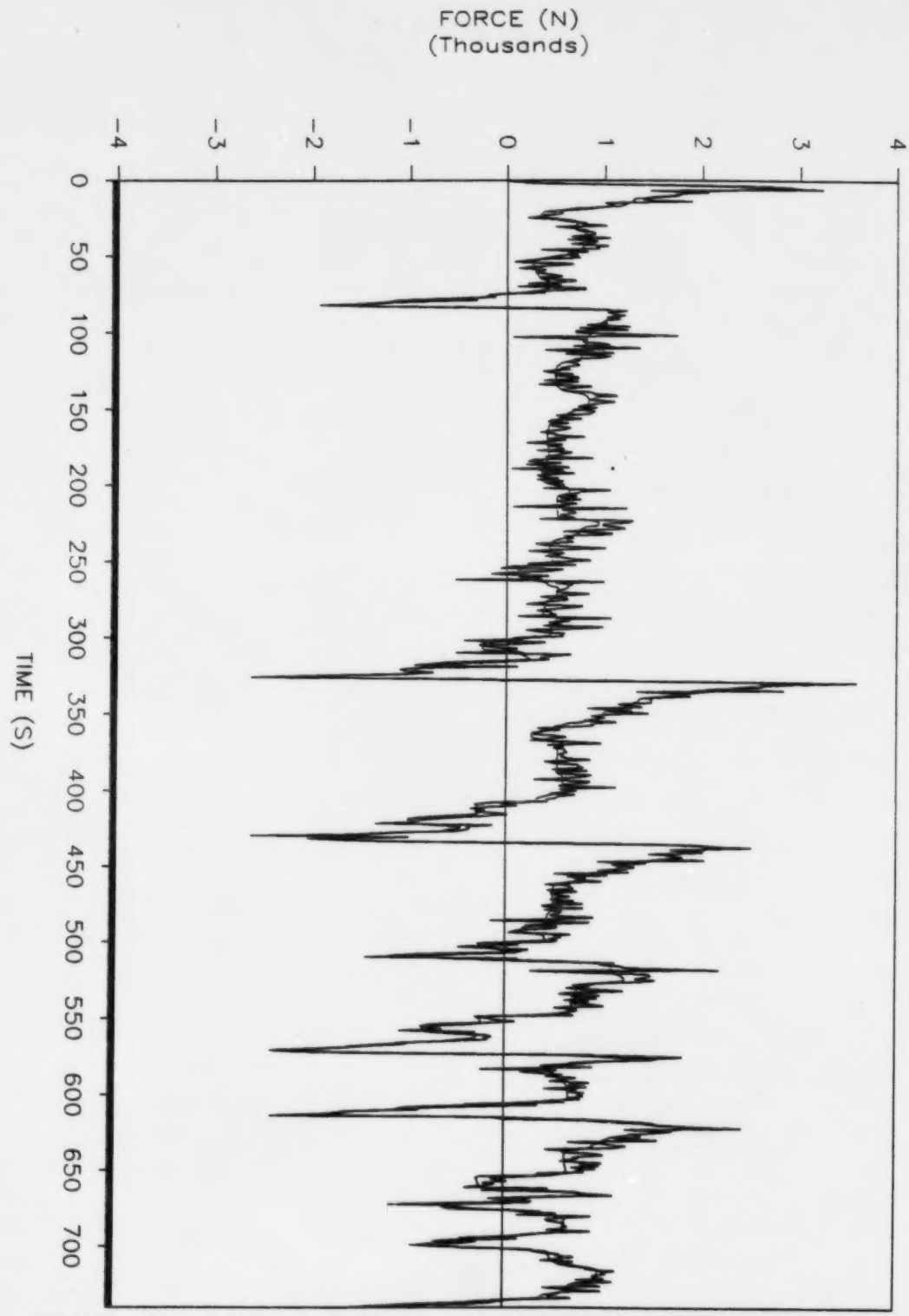

FIGURE 3.20 ROAD LOAD FORCE, PEAK FILTERED TWICE VS TIME AND WHEEL TORQUE SENSOR FORCE VS TIME, WINTER DATA

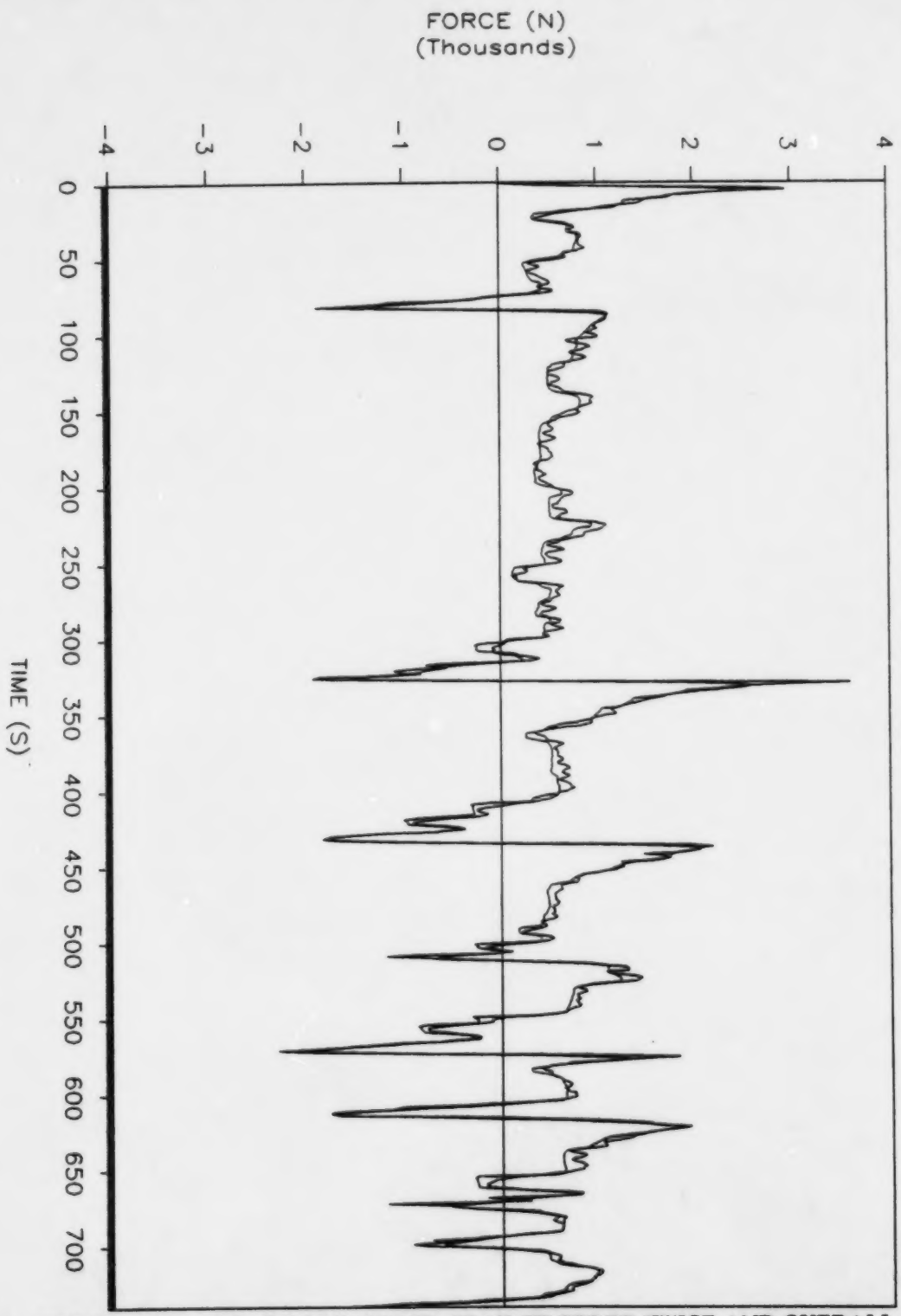

FIGURE 3.21 ROAD LOAD FORCE, PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, AND WHEEL TORQUE SENSOR FORCE VS TIME, WINTER DATA

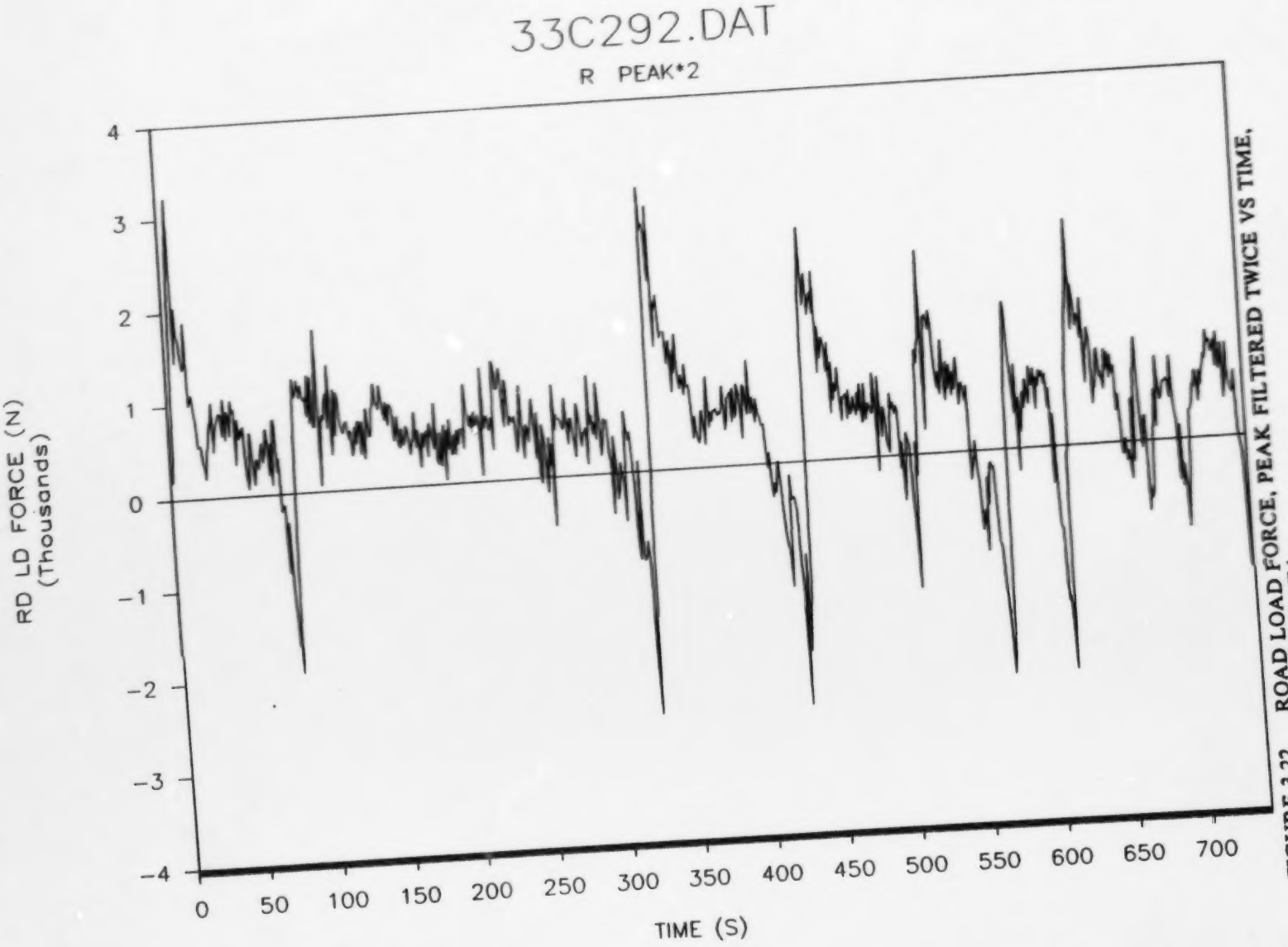

FIGURE 3.22 ROAD LOAD FORCE, PEAK FILTERED TWICE VS TIME, WINTER DATA

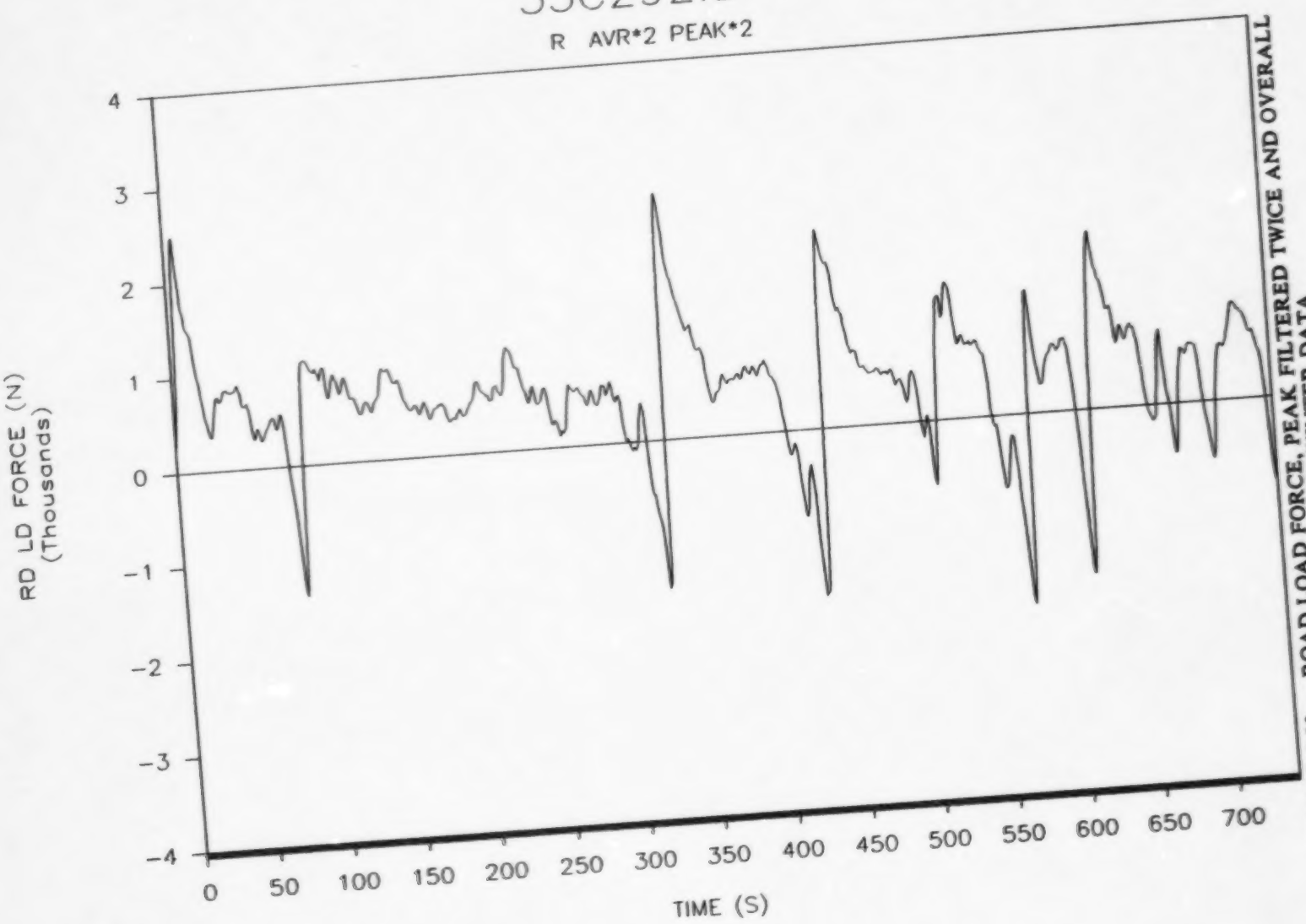

FIGURE 3.23 ROAD LOAD FORCE, PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, WINTER DATA

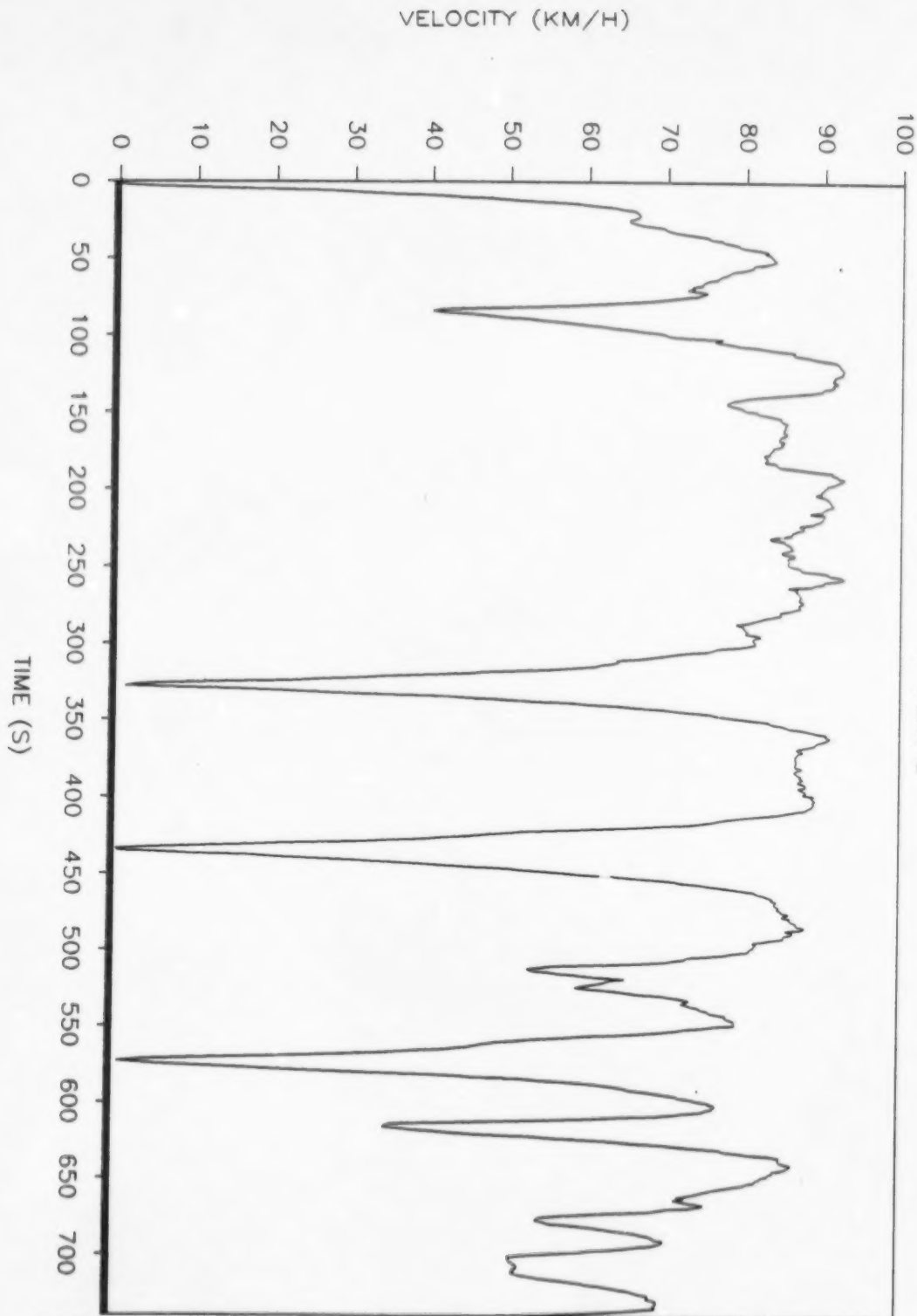

FIGURE 3.24 VELOCITY PEAK FILTERED TWICE VS TIME, WINTER DATA

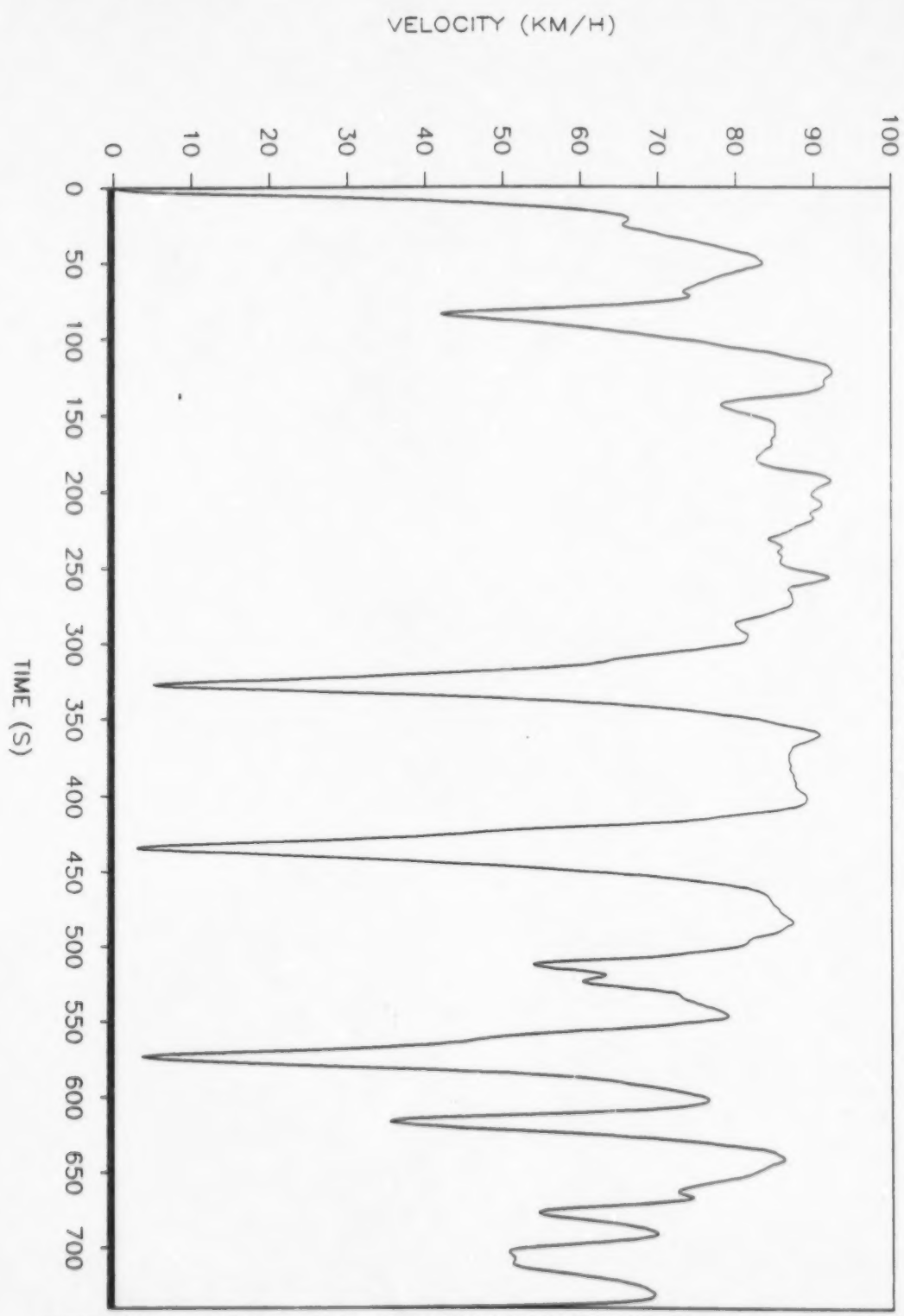

FIGURE 3.25 VELOCITY PEAK FILTERED TWICE AND OVERALL FILTERED VS TIME, WINTER DATA